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Preliminary Report on
GROUND-WATER RESOURCES OF THE CHICAGO REGION, ILLINOIS

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PRELIMINARY REPORT ON GROUND-WATER RESOURCES OF THE CHICAGO REGION, ILLINOIS

MAX SUTER, ROBERT E. BERGSTROM, H. F. SMITH,
GROVER H. EMRICH, W. C. WALTON, and T. E. LARSON

STATE WATER SURVEY STATE GEOLOGICAL SURVEY

COOPERATIVE GROUND-WATER REPORT I

URBANA, ILLINOIS 1959

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FOREWORD

This report initiates a joint series of publications designed to present results of ground-water resource investigations carried on cooperatively by the State Water Survey and the State Geological Survey. It is indeed fitting that the first in this series deals with the ground-water resources of the Chicago region in Illinois. Within this part of Illinois there occurs not only the greatest concentration of people and of industries, but also the largest withdrawals of ground water in relation to area.

It should be pointed out that this report presents preliminary findings based largely on data collected independently by the two Surveys over a period of several decades. The urgent need for continuing integrated research on ground-water resources of this region is clearly apparent, and, within the limitations of their financial resources, the Geological and Water Surveys are planning to carry forward a series of such joint studies.

It also is anticipated that cooperative studies already started or in the planning stage for other parts of the state will result in reports in this new series, with the ultimate objective of a satisfactorily thorough knowledge of the ground-water resources of all parts of Illinois.

William C. Ackermann
Chief, Illinois State Water Survey

John C. Frye
Chief, Illinois State Geological Survey

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PRELIMINARY REPORT ON

GROUND-WATER RESOURCES OF THE CHICAGO REGION, ILLINOIS

MAX SUTER, ROBERT E. BERGSTROM, H. F. SMITH,
GROVER H. EMRICH, W. C. WALTON, and T. E. LARSON

ABSTRACT

The purpose of this study was to make an evaluation of the ground-water resources of the Chicago region on the basis of available data. Such an evaluation is particularly urgent at this time due to the progressively increasing demands for water supplies and the continuing decline of water levels in some aquifers.

Ground-water resources in the Chicago region of Illinois are developed from four water-yielding units: 1) glacial drift aquifers; 2) shallow dolomite aquifers; 3) Cambrian-Ordovician Aquifer; and 4) the Mt. Simon Aquifer.

The Cambrian-Ordovician Aquifer has been the most highly developed source of large ground-water supplies. Its estimated yield in 1958 of more than 43 million gallons a day (mgd) approaches the amount that can be withdrawn without dewatering the Ironton-Galesville Sandstone, the lowermost and most productive formation in the aquifer. Artesian pressure in the Cambrian-Ordovician Aquifer at Chicago has declined as much as 660 feet since 1864 as a result of pumpage.

The glacial drift and shallow dolomite aquifers yielded more than half of the 127.9 mgd of ground water pumped in the region in 1957. This withdrawal resulted in no general decline in nonpumping water levels, indicating that the potential yield is considerably larger than present withdrawal. Future ground-water supplies should be taken from the shallow aquifers wherever possible.

SUMMARY

The Chicago region as defined in this report consists of Cook, DuPage, Kane, Kendall, Lake, McHenry, and a portion of Will and Grundy Counties of northeastern Illinois. The region is the most densely populated and heavily industrialized area in Illinois. Compared to the state as a whole, the region contains only 7.5 percent of the land area but has 61.3 percent of the population. It has been one of the most favorable ground-water areas in the state. However, the tremendous industrial and municipal growth in the region has brought about local problems of water supply.

Some 110 municipalities not served by water from Lake Michigan obtain supplies from wells. Many industries, including a large number of plants within the area served by Lake Michigan water, have private wells and use ground water for processing and cooling.

Ground-water resources in the region are developed from four aquifer systems: 1) sand and gravel deposits of the glacial drift; 2) shallow dolomite formations, mainly of Silurian age; 3) Cambrian-Ordovician Aquifer, of which the Ironton-Galesville and Glenwood-St. Peter Sandstones are the most productive formations; and 4) the Mt. Simon Aquifer, consisting of the sandstone of the Mt. Simon and lower Eau Claire Formations of Cambrian age.

Unconsolidated deposits, mainly glacial drift, ranging in thickness from a foot or less to more than 400 feet, overlie the bedrock in the Chicago region. Water-yielding sand and gravel deposits locally occur in the drift, particularly in valleys cut in the bedrock.

Silurian age dolomite, which is widely used as a source of ground water, is the uppermost bedrock formation in most of the region. The bedrock formations dip slightly south of east at a rate of about 10 feet per mile. They are warped into minor folds and at some places are faulted. There is no indication that the folds or faults act as barriers to the regional movement of ground water.

The glacial drift and shallow dolomite aquifers are connected hydrologically and are separated from the Cambrian-Ordovician Aquifer in most of the region by the Maquoketa Formation, mainly shale, of Ordovician age. The relatively impermeable parts of the Eau Claire Formation separate the Cambrian-Ordovician from the Mt. Simon Aquifer.

Pumpage in the region in 1957 was 127.9 million gallons per day (mgd) of which 72.4 mgd were from deep wells penetrating the Cambrian-Ordovician Aquifer and, locally, the Mt. Simon Aquifer, 41.2 mgd were from wells finished in the shallow dolomite, and 14.2 mgd were from wells finished in the glacial drift. It was estimated that about 27 percent of the water pumped from deep wells comes from the shallow dolomite or glacial drift aquifers, thus making the present yield of the shallow aquifers about 60 percent of the total pumpage in the region.

The Cambrian-Ordovician Aquifer has been the most highly developed aquifer for large ground-water supplies in the Chicago region and is considered in most detail in this report. Artesian pressure in the aquifer at Chicago has declined as much as 660 feet since 1864 to a low of 50 feet above sea level, an average rate of decline of about seven feet per year. There are now six pronounced cones of depression in the region. Little decline has occurred west of the border of the Maquoketa Formation, and the presence there of a hydrologic connection between the Cambrian-Ordovician Aquifer and the shallow aquifers is indicated. A large part of the recharge to the Cambrian-Ordovician Aquifer is from this area. This is further substantiated by the low temperature and low sulfate content of water from the Cambrian-Ordovician Aquifer in the area. This part of the Chicago region is the most favorable for further development of deep wells.

Data from 63 pumping tests were analyzed to determine the hydraulic properties of the Cambrian-Ordovician Aquifer. The average coefficient of transmissibility was determined to be 17,400 gallons per day per foot. Coefficients of transmissibility decrease to the southeast. A coefficient of storage of 0.0006 applies for periods of pumping involving several years or more.

In making estimates of future water levels in the Cambrian-Ordovician Aquifer, a recharge boundary 47 miles west of Chicago and two barrier boundaries, one 37 miles east, and one 60 miles south of Chicago, were assumed. It was estimated that the practical sustained yield of the aquifer is about the present rate of withdrawal.

Based on the assumption that total pumpage from deep wells will increase to about 92 mgd in 1980, water levels will decline at Chicago to an elevation of about 250 feet below sea level, which will be sufficient to dewater much of the upper part of the Cambrian-Ordovician Aquifer. Predictions of future water levels are based in part on extrapolations of past ground-water use in the region. Future conditions may vary from the general findings of the report in local areas where the distribution and rates of pumping are not as assumed.

The Mt. Simon Aquifer contains water that is under greater artesian pressure but is more highly mineralized than water in the Cambrian-Ordovician Aquifer. Proper plugging of abandoned deep wells to prevent upward movement of the water from the Mt. Simon Aquifer is necessary to protect the highly developed Cambrian-Ordovician Aquifer.

Hydrographs indicate no general or permanent decline in water levels in wells finished in the shallow aquifers. The fact that there has been no water-level decline even in the areas of heaviest pumpage indicates that the potential yield of the shallow aquifers probably is considerably larger than the present withdrawal of more than 75 mgd. Therefore the shallow aquifers are the most likely sources to investigate for additional ground-water supplies. Additional study is necessary to delineate favorable areas for further ground-water development and to determine the potential yield of the shallow aquifers.

The temperature of water from the shallow aquifers averages 51.6°F. The hardness of the water ranges from less than 100 parts per million (ppm) to more than 1000 ppm.

The temperature of water from the Cambrian-Ordovician Aquifer ranges from about 53°F. in the western part of the region to about 62°F. in the eastern part. The hardness increases from about 290 ppm in the central part of the region to about 800 ppm in the eastern part.

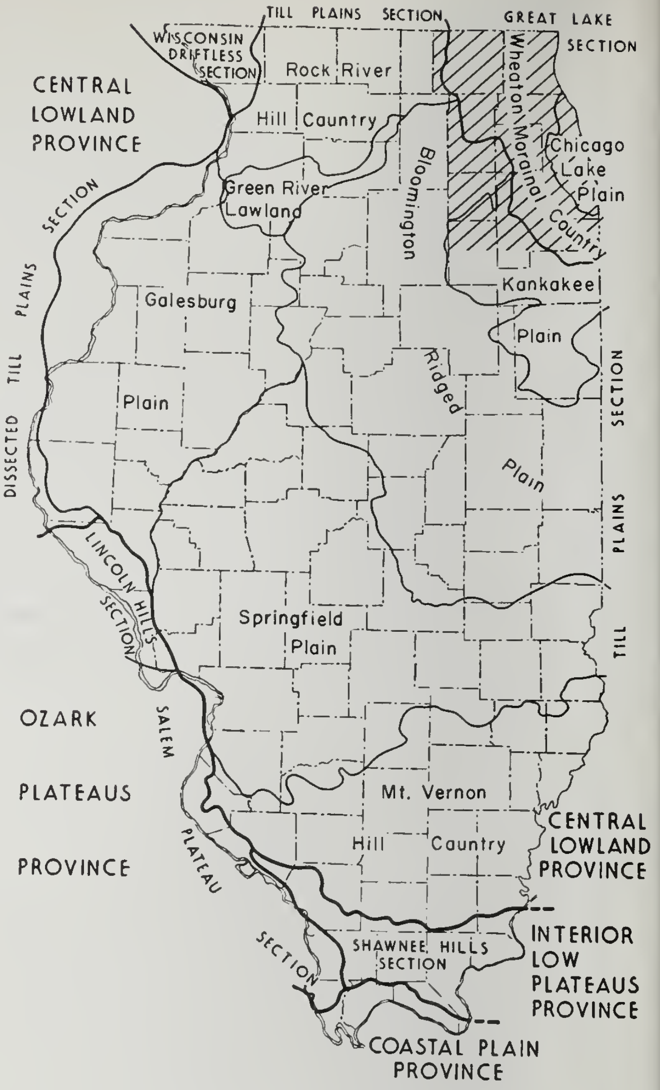


Fig. 1. Location of the Chicago region and physiographic divisions of Illinois.

Water from the Mt. Simon Aquifer appears to increase in temperature by about one degree per 100 feet of additional depth below an elevation of 1300 feet below sea level where the temperature is 66°F. The primary characteristic of the quality of water from the Mt. Simon Aquifer is the rapid increase in chloride concentration with depth. Deeper than an elevation of about 1300 feet below sea level, water from the Mt. Simon Aquifer is too highly mineralized for most purposes.

Further geologic and hydrologic studies are recommended, relating to quantitative evaluations of the shallow aquifers, detailed stratigraphy of the deeper formations, effects of dewatering parts of the Cambrian-Ordovician Aquifer, effects of Lake Michigan on possible recharge, and the relations between the Chicago and Milwaukee pumpage cones.

INTRODUCTION

The Chicago region has been one of the most favorable round-water areas in Illinois. It is underlain at depths f 500 feet and more by sandstone aquifers that have een prolific sources of water for nearly 100 years. In rly days of ground-water development in the region, ughly before 1895, wells drilled to the aquifers were pecially desirable because the sandstones yielded wa- r of excellent quality with enough artesian pressure cause water to flow at the surface without pumping. t lesser depths the Chicago region is underlain by acial deposits and creviced dolomite that locally are cellent sources of ground water.

The diversity of water sources has promoted indus- ial expansion of the region and also facilitated urban owth. Large users of water obtain supplies from deep ck wells when water is not available from Lake Michi- n and other surface sources. Small users of water, ch as suburban residences or farms, obtain adequate ater at reasonable cost from shallow wells finished in e glacial deposits or underlying creviced dolomite.

However, the tremendous industrial and municipal owth in the Chicago region has brought about local oblems of water supply. Exploitation of the deep rock uifers has lowered water levels in some areas to the int where pumping costs are restricting further de- lopment at present water rates. The expansion of burban residential areas with individual sewerage stems and wells has in some areas adversely affected allow ground-water sources.

Purpose and Scope

This report is based on all data on file at the Illinois ate Water Survey and the Illinois State Geological rvey and on other published reports. It presents the drologic and geologic factors along with history, esent conditions, and effects of possible future de- opment on the ground-water resources of the Chicago gion. Special emphasis is placed on the most heavily veloped deep sandstone aquifers. Basic geologic, drologic, and chemical data applicable to local prob- ns and to regional and long-range interpretations are esented to help formulate future policy on water re- irce planning and development in northeastern Illinois.

The investigation was begun in 1942 with a program collect data in the Chicago region. Data on water els, pumpage, mineral quality of water, and well ts were collected by the State Water Survey. Well s, drilling samples, geophysical logs and other geo- ic information were collected by the State Geological rvey.

Although the report summarizes present-day knowl- ge of ground-water conditions in the Chicago region, must be considered a preliminary report in the sense t it is part of a continuing study of the Chicago re- n ground-water resources, and its conclusions and interpretations will be modified and expanded as more data are obtained.

All elevations given in this report refer to mean sea level (m.s.l.), 1929 general adjustment, Coast and Geodetic Survey.

Previous Reports

The geology and water resources of the region have received considerable study and many reports have been published. The major reports are listed in the Selected References at the end of the report.

Acknowledgments

Many persons and organizations have assisted in the collection of data and preparation of the report for this investigation. Much of the basic data was collected by Jacob S. Randall, J. G. Geils, John B. Millis, Robert T. Sasman, and W. J. Wood, of the Water Survey and Lowell A. Reed and Arthur J. Zeizel of the Geological Survey.

W. H. Voskuil prepared the section on economy. George E. Ekblaw prepared the map of glacial geology and a portion of the map of bedrock topography. John W. Hawley helped prepare the maps showing the thickness of the unconsolidated deposits and the Silurian rocks. All three are staff members of the Geological Survey. Stanley A. Changnon, Jr., of the Water Survey prepared the material on climate. Helpful suggestions and criticisms were given, particularly by G. B. Maxey but also by many individuals from both Surveys, during the course of the investigation.

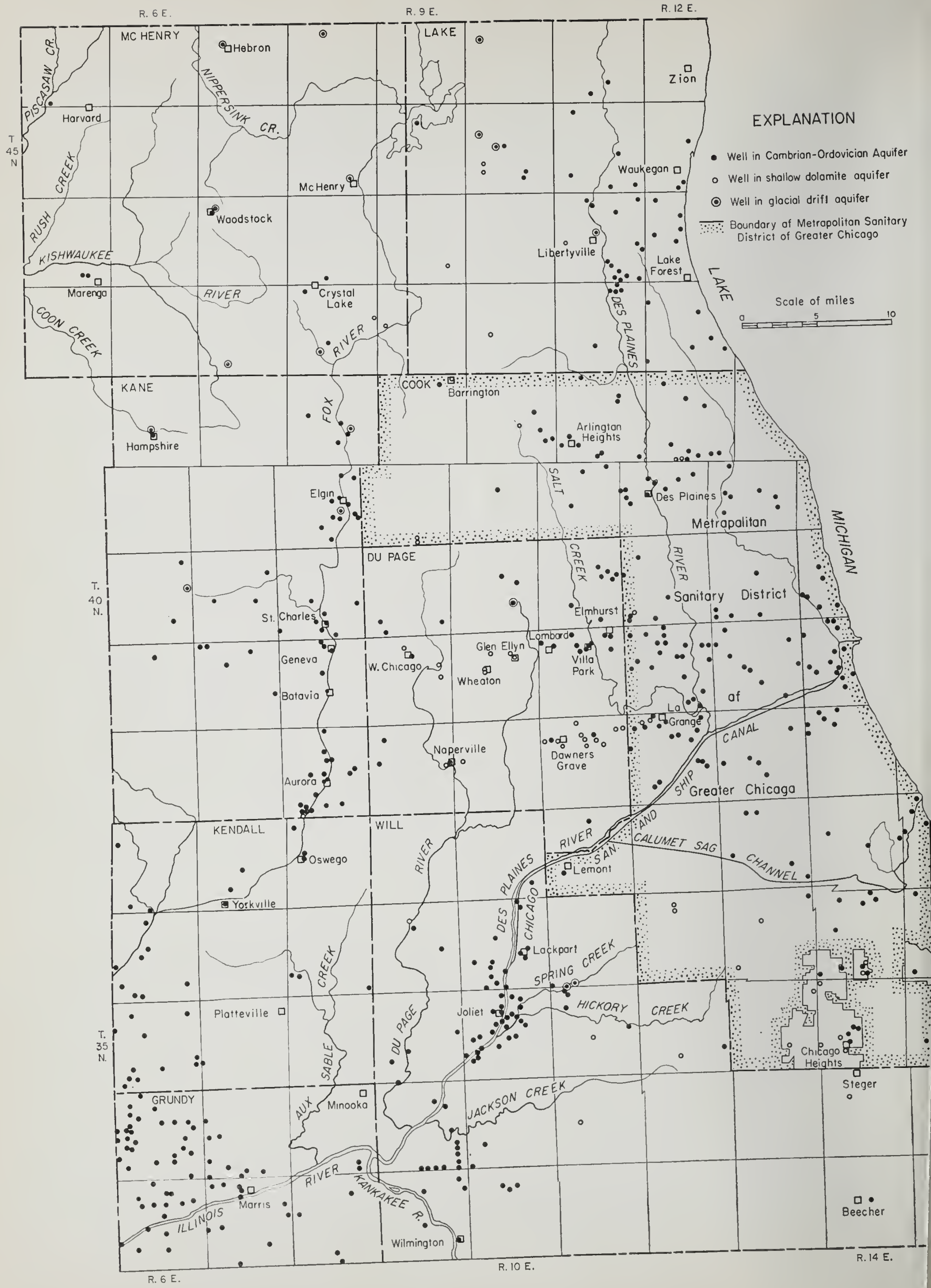
The Wisconsin Geological Survey and the Ground-Water Branch of the United States Geological Survey at Madison generously gave the authors access to logs and hydrographs of wells in southeastern Wisconsin.

This report would have been impossible without the generous cooperation of municipal officials, industries, engineers, and water-well contractors who provided information on wells, water levels, and pumpage.

Location and General Features

The Chicago region of Illinois described in this report includes Cook, DuPage, Kane, Kendall, Lake, and McHenry Counties, and the parts of Grundy and Will Counties north of the north boundary of T. 32 N. (figs. 1 and 2). Quadrangle topographic maps of this area have been prepared under a cooperative arrangement between the United States Geological Survey and the Illinois State Geological Survey. Figure 3 is an index map showing the location of the quadrangles.

The region is the most densely populated and heavily industrialized section of Illinois. The area and population are given in table 1. The region under consideration contains only 7.5 percent of the land area of the state of Illinois but has 61.3 percent of the population.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R. 9 E.
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LAKE
Hebron
Zion
PISCASAW CR.
NIPPERSINK CR.
Harvard
T. 45 N.
RUSH CREEK
McHenry
Waukegan
Woodstock
KISHWAUKEE
RIVER
Libertyville
Lake Forest
Marenga
Crystal Lake
COON CREEK
FOX RIVER
DES PLAINES
LAKE
KANE
COOK
Barrington
Arlington Heights
Hampshire
SALT CREEK
Elgin
Des Plaines
Metropolitan
MICHIGAN
DU PAGE
RIVER
T. 40 N.
Sanitary District
Elmhurst
St. Charles
Lombard
Glen Ellyn
Villa Park
Geneva
W. Chicago
Wheaton
Batavia
of
La Grange
CANAL
Naperville
Downers Grove
SHIP
Aurora
Greater Chicago
AND
KENDALL
WILL
RIVER
RIVER
DES PLAINES
SAN
CALUMET SAG CHANNEL
Oswego
Lemont
Yorkville
CHICAGO
CREEK
Lockport
SPRING CREEK
Platteville
Joliet
HICKORY CREEK
DU PAGE
T. 35 N.
SABLE
Chicago Heights
Steger
GRUNDY
AUX
Minooka
JACKSON CREEK
RIVER
KANKAKEE R.
ILLINOIS
Morris
Beecher
Wilmington
R. 6 E.
R. 10 E.
R. 14 E.
EXPLANATION
● Well in Cambrian-Ordovician Aquifer
○ Well in shallow dolomite aquifer
◉ Well in glacial drift aquifer
Boundary of Metropolitan Sanitary District of Greater Chicago
Scale of miles
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TABLE I. AREA AND POPULATION OF THE CHICAGO REGION BY COUNTY

County	Area in square miles	1950* Population	1950* Population per square mile	1957† Population	1957† Population per square mile
Cook	954	4,508,792	4,726	5,028,800	5,270
DuPage	331	154,599	467	249,100	750
Part of Grundy	210	11,520	55	16,300	78
Kane	516	150,388	291	179,300	348
Kendall	320	12,115	38	14,200	44
Lake	457	179,097	392	251,300	550
McHenry	611	50,656	83	69,400	113
Part of Will	770	131,097	170	171,400	213
Totals for Region	4,169	5,198,264	1,247	5,979,800	1,432
State of Illinois	55,947	8,712,176	156	9,754,000	174

* U. S. Bureau of the Census.
† Illinois Department of Public Health estimates.

According to the 1954 Census of Manufactures, the eight counties under study had 13,279 manufacturing establishments producing goods valued, after deduction of labor and supply costs, at $7,010,865,000 that year. The state as a whole had 17,628 manufacturing establishments with a net production value of $9,668,752,000. Thus the Chicago region has 75.2 percent of the state's manufacturing establishments and produced 72.5 percent of the value added by manufacturing.

The vast economic importance of the area is a result of many factors (Fryxell, 1927, p. 1-10): 1) it is near the center of one of the richest agricultural belts in the world; 2) favorable terrain and location have made Chicago a major railway and highway center; 3) the Great Lakes afford a water transportation system that links Chicago with the other great ports of the world; 4) the Chicago Drainage Canal and the Calumet-Sag Channel connect Chicago with the Illinois and Mississippi River systems; 5) adequate resources and moderate climate are favorable for supporting a large population.

All cities that border Lake Michigan in the Chicago region, except Lake Bluff, Zion, and Winthrop Harbor, obtain water supplies from the lake. The City of Chicago, which serves about 60 municipalities and pumps more than a billion gallons a day from the lake, is the largest user of water.

Some 110 municipalities not served by water from Lake Michigan obtain supplies from wells. Suburban and rural water supplies beyond the municipal distribution system are obtained from ground water. Many industries, including a large number of plants within the area served by Lake Michigan water, have private wells and use ground water for processing and cooling. Some industrial water is obtained from surface sources other than Lake Michigan.

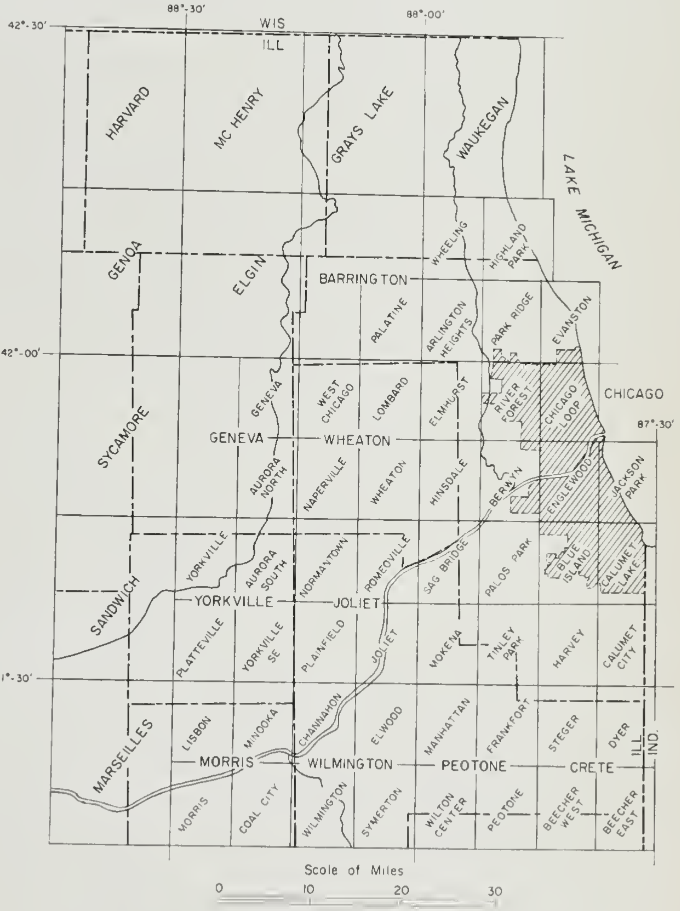


Fig. 3. Quadrangle topographic maps of the Chicago region.

Fig. 2. Chicago region with location of selected wells. Shown are most wells in Cambrian-Ordovician Aquifer for which geologic or hydrologic records are on file at the State Surveys. Only a few wells in shallow dolomite and glacial drift aquifers, representative of the several thousand for which records are on file, are shown. See Appendix B for summaries of well data.

GEOGRAPHY

Topography

The Chicago region lies near the center of the physiographic Central Lowland Province, a glaciated lowland that stretches from the Appalachian Plateau on the east to the Great Plains of Kansas, Nebraska, and the Dakotas on the west. It includes five physiographic subdivisions (fig. 1): 1) the Chicago lake plain, 2) the Wheaton morainal country, 3) the Kankakee plain, 4) the Bloomington ridged plain, and 5) the Rock River hill country.

The Chicago lake plain, extending from Indiana as far north as Winnetka and as far west as LaGrange, is a low, flat surface sloping gently toward the lake, interrupted by a few low ridges and knolls and by two large valleys along the Des Plaines River and Sag Channel (figs. 2, 4). Low, discontinuous ridges (fig. 5, in pocket) on the lake plain mark the position of three former levels of Glacial Lake Chicago, the ancestor of Lake Michigan. The highest and earliest beach ridge, the Glenwood stage shore line, has an elevation of about 635 feet or 55 feet above present lake level (fig. 6, in pocket). About 20 feet lower (615-foot elevation) is the Calumet stage shore line, and about 15 feet still lower (600-foot elevation) is the Toleston stage shore line. Present lake level is about 580 feet.

Bordering the lake plain to the north, west, and south is the Wheaton morainal country, characterized by hilly topography, broad parallel morainic ridges, lakes, and swamps (figs. 5 and 6). This is the most extensive physiographic subdivision in the region, and includes most of Lake, McHenry, DuPage, and Will Counties. It also contains the highest land, for extensive tracts in Kane and McHenry Counties are more than 900 feet above sea level. The highest point in the region, four miles northeast of Harvard, is 1192 feet.

The Kankakee plain, including western Will, southeastern Kendall, and Grundy Counties, is a level to gently undulatory plain that occupies the position of a basin between higher morainic country to the west and east. Low ridges, terraces, bars, and dunes locally rise above the general level.

The Bloomington ridged plain lies west of the Kankakee plain. Only the northeastern part of it, in southwestern Kane and northwestern Kendall Counties, is within the region covered by this report. It is characterized by broad, morainic ridges with intervening wide stretches of relatively flat or gently rolling plains. Lakes and swamps are less common than in the Wheaton morainal country.

The Rock River hill country extends into the area of this report only in western McHenry County and the northwest corner of Kane County. It is characterized by rolling hills, thin glacial drift, and narrow valleys.

Fryxell (1927, p. 1-10), Bretz (1955, p. 27-41), and Leighton, Ekblaw, and Horberg (1948, p. 21-26) present descriptions of the physiography of the region.

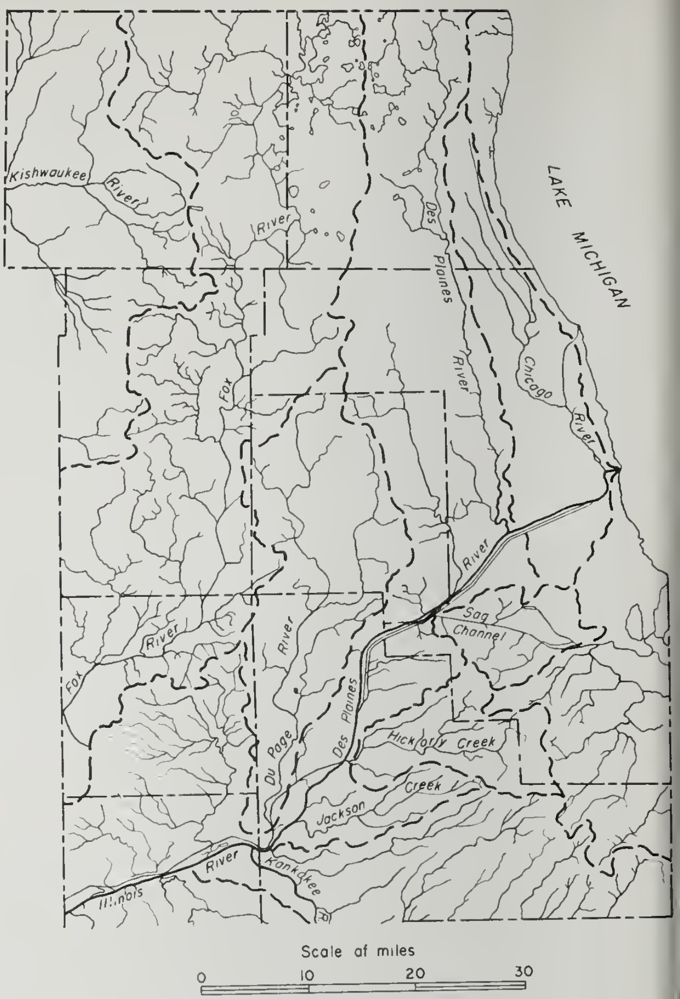


Fig. 4. Drainage and watersheds of the Chicago region.

Drainage

The drainage map of the Chicago region (fig. 4), showing all streamways however slightly incised, has many blank areas, indicating poor drainage. Much of the morainal country is without integrated drainageways and still has the constructional slopes that were fashioned by the glaciers. Swamps and lakes are common. Most of the lake plain is without natural drainageways.

The drainage divide between the Great Lakes an the Mississippi River systems crosses the region onl a few miles from the lake (fig. 4). About 68 squar miles along Lake Michigan north of downtown Chicag and some 294 square miles around and south of Calumet Lake drain into Lake Michigan. The remainder o the region drains into the Mississippi River system 465 square miles through the Kishwaukee-Rock Rivers and 3,342 square miles through the Illinois by way o the Des Plaines, DuPage, Fox, and Kankakee Rivers.

TABLE 2. HIGHEST AND LOWEST MONTHLY PRECIPITATION DURING 1938-1957

Months	Highest			Lowest		
	Precipitation	Station	Year	Precipitation	Station	Year
January	5.38	Park Forest	1949	0.11	Antioch	1956
February	4.84	Park Forest	1950	0.10	Antioch	1947
March	7.23	Wheaton	1948	0.33	Newark	1956
April	9.72	Channahon Island	1950	0.49	McHenry	1942
May	9.18	Peotone	1943	0.49	Arlington Heights	1950
June	10.65	Wheaton	1939	0.70	Chicago University	1956
July	10.73	Peotone	1957	0.02	Morris	1940
August	9.65	Waukegan	1945	0.46	Newark	1953
September	10.62	Waukegan	1945	0.15	McHenry	1940
October	14.86	Aurora	1954	T	Waukegan	1952
November	5.57	Aurora	1942	0.34	Aurora	1949
December	7.11	Joliet	1949	T	Wheaton	1943

CLIMATE

Precipitation, evaporation, and temperature are the most commonly measured climatic factors that are directly related to the availability, storage, movement, and withdrawal of ground water. Precipitation adds water to the land and evaporation takes it away. Temperature influences evaporation and infiltration and also affects the rate and distribution of ground-water withdrawal.

The climate of the Chicago region is classified as continental with warm summers and cold winters. Precipiation, evaporation, and temperature vary with the latitude. Aside from local influences, such as Lake Michigan and the large urban area of Chicago, the average annual precipitation for the period 1938-1957 ranged from about 32 inches in the north to about 36 inches n the southeast (fig. 7) and the average annual temperature ranged from about 48°F. to 51°F. (fig. 8).

Precipitation varies through a wide range in intenity, geographic distribution, and frequency of storms. During the period 1938-1957, June was the wettest month with 4.15 inches of rain and February was the riest, with 1.7 inches. Highest and lowest precipitation for each month for the 20-year period, regardless f location, are shown in Table 2. The table illustrates the wide variation in amount of precipitation that may e expected for a given month over a number of years. The greatest range shown in the table is for October when a trace of precipitation was recorded at Waukegan n 1952 whereas 14.86 inches of precipitation were recorded at Aurora in 1954.

On the average, 120 days per year have measurable precipitation. The average annual snowfall is 31 inches, nd normally nine days each winter have snowfall of more than one inch.

The Chicago region has a wide seasonal range of emperatures. January, the coldest month, had a ean temperature of 25.1 degrees, ranging from 22.7 egrees at Antioch to 27.2 degrees at Joliet. July, the armest month, had a mean temperature of 74.1 degrees, ranging from 75.5 degrees at Joliet to 72.4 degrees at Antioch.

During the period of frequent and persistent daily temperatures below freezing little or no recharge to the ground-water reservoir occurs because much of the time the ground is frozen and relatively impermeable. During the 1938-57 period the region averaged 90 days per year with mean daily temperatures below freezing.

The length of the growing season also influences recharge because plants intercept most of the water soaking into the soil zone during this period. The growing season for the Chicago region ranges from 150 to 180 days with most of the region in the 160- to 170-day range. The average dates of beginning and end of the growing season (the period between killing frosts) occur in late April or early May and in October, respectively.

Temperatures during the summer months directly influence ground-water pumpage because ground water

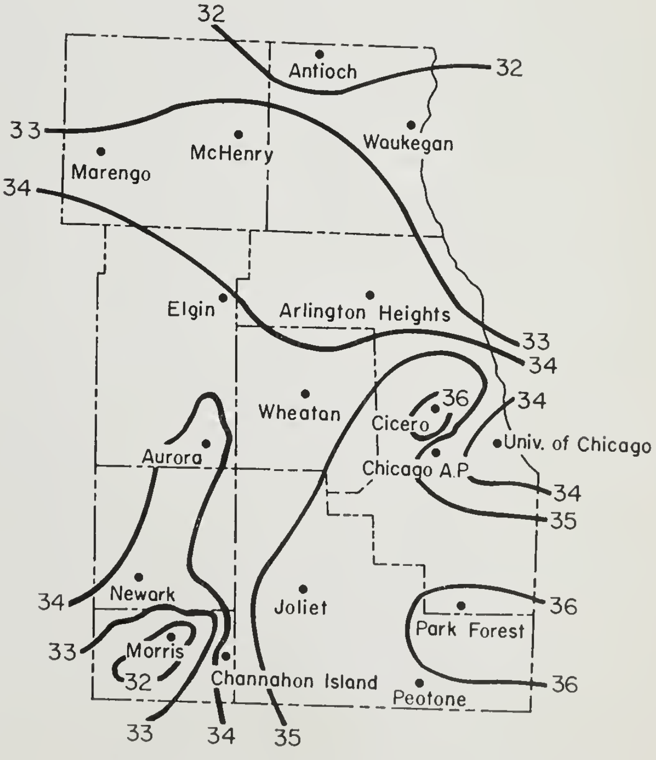


Fig. 7. Average annual precipitation in the Chicago region.

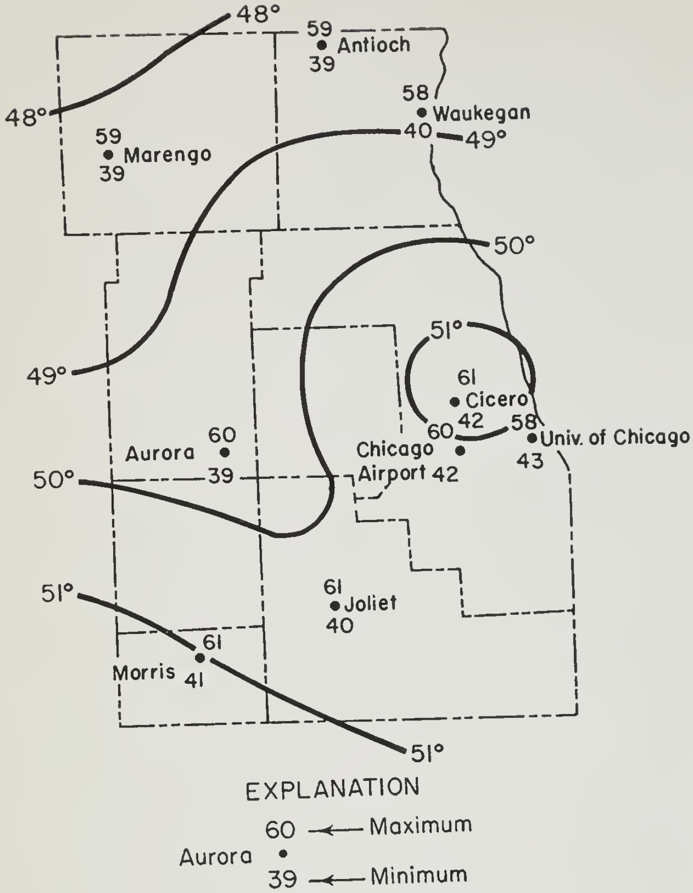


Fig. 8. Mean annual temperature in the Chicago region.

is widely used for air conditioning and other cooling purposes in the Chicago region. To estimate the magnitude of cooling requirements, a classification of cooling degree days is used and computed on a daily basis by subtracting 75 degrees from the mean daily temperature. For the months during which cooling degree days normally occur, the average and extreme values for Chicago are shown in figure 9. On an annual basis, Chicago averages 139 cooling degree days per year. The annual average in the eight county area ranges from 80 in northeastern Lake County to approximately 150 per year in southwestern Grundy County.

In general, recharge from precipitation to the ground-water reservoir is greatest in the spring, that is, after the ground thaws and before vigorous plant growth begins. This has been substantiated by observations of water-levels in the Chicago region and also in adjacent areas. It has been estimated that about 10 to 12 percent of the annual precipitation reaches the ground-water reservoirs in Illinois, and it is reasonable to believe that recharge in the Chicago region is within this order of magnitude. More study is needed to determine accurately the amount of recharge in the region.

Population

The pattern of population controls ground-water use. In the Chicago region the large urban area is the main factor. The extension of urban areas affects ground-water conditions in the following ways: 1) newly built-up areas obtain water supplies from many individual wells whose combined effect increases pumpage over a widespread area; 2) such areas later develop communal water supplies that increase local concentrations of pumpage; 3) urbanization may affect ground-water recharge and is known to alter the run-off relationships of the natural terrain.

The first settlements in the Chicago area were at the mouth of the Chicago River where Fort Dearborn was built in 1803. Cook County was established in 1831 and the other seven counties of the area within the following 10 years.

The growth of the population in the region is shown in figures 10 and 11, which also show the predominance of the population of Chicago compared with that of the rest of the state. The region under consideration has had one-half the state's population since 1914, and Cook County has had more than one-half the state's population since 1927. Population is given in table 1, p. 11.

The growth of urban areas in Illinois has accompanied the growth in population, especially in the last 30 years. Much of the urban growth has taken place in suburbs of the larger cities.

Economy

The economy of northeastern Illinois is based on manufacturing, agriculture, and mining, named in the

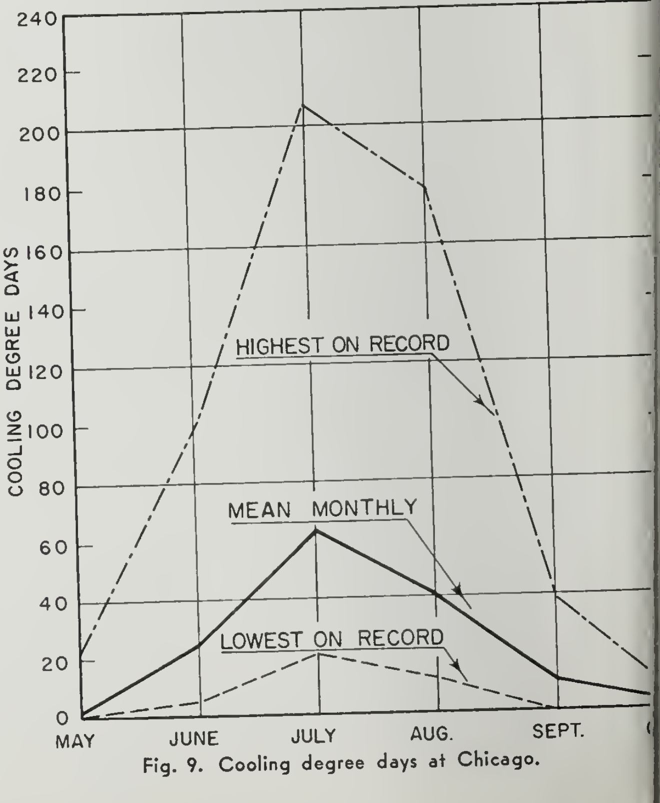
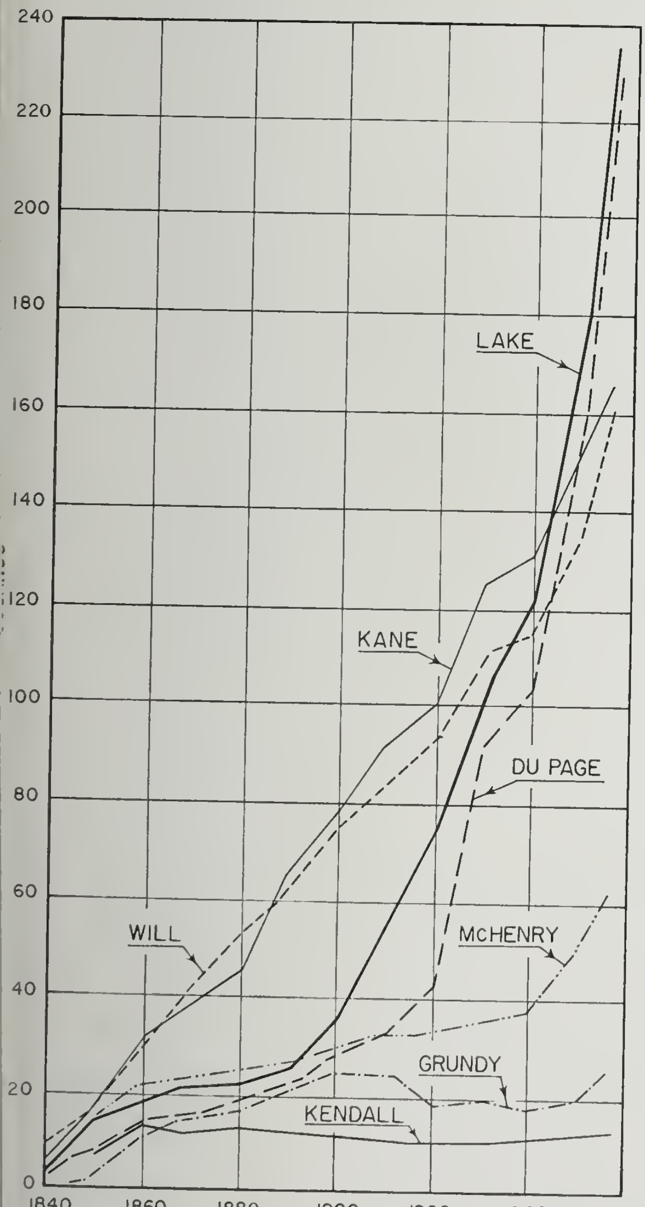


Fig. 9. Cooling degree days at Chicago.

rder of value of output. In addition, Chicago is the ocal point for vast rail and truck systems and for peroleum and natural gas pipelines that transport raw naterials into the Chicago industrial district and also listribute the products manufactured from these raw aaterials.

Of the 20 manufacturing groups in the Chicago area lassified by the Census of Manufactures for 1954, the ron and steel industry is the largest and is also the argest industrial user of ground water.

Food processing, including the meat, dairy products, anned and frozen goods, grain mill products, and bakry products industries, ranks second to the metal working industries in northeastern Illinois in terms of number employed and wages paid and these industries are the second largest industrial users of ground water.



10. Growth of population by county (except Cook). Data from . Census; 1956 estimate from Illinois Department of Public Health.

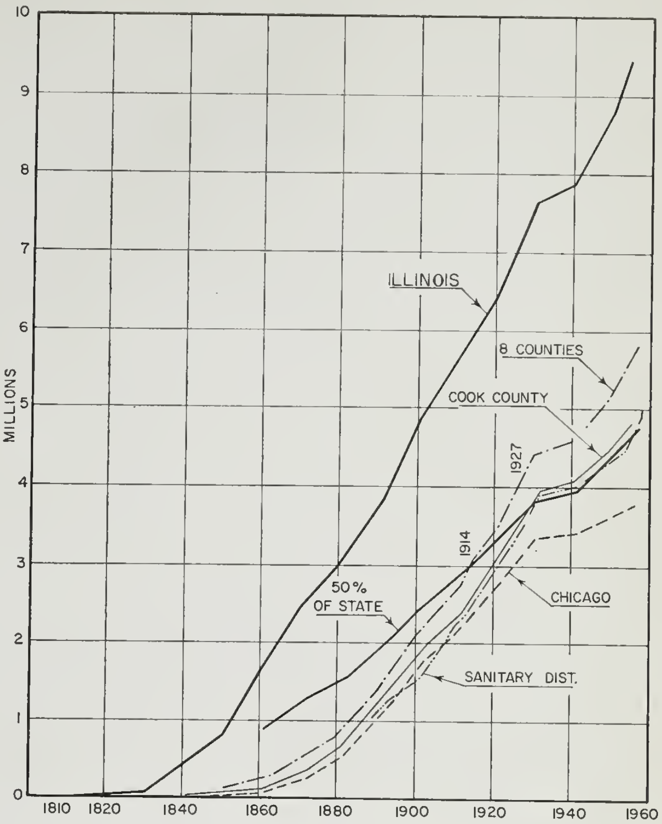


Fig. 11. Growth of population of region compared with that of Illinois. Data from U. S. Census; 1956 estimate from Illinois Department of Public Health.

Chicago is the second largest printing and publishing center in the nation. Commercial printing is the largest branch of the industry, followed by newspaper publishing and lithographing.

The manufacture of apparel, chemicals, petroleum products, furniture, and pulp and paper follow in order of value of output.

Electric utility power plants in the Chicago area, including plants at Waukegan, Aurora, Joliet, and Lockport, have a capacity of 3,000,000 kilowatts and an annual electric power output of approximately 15 billion kilowatt hours. Electric power plants use large amounts of surface water but only minor amounts of ground water.

Agriculture also is of considerable importance in northeastern Illinois. The eight counties in the region have 2,027,000 acres, or 71 percent of the area, in farms, compared with 86.5 percent for the state as a whole. In the dominantly agricultural counties of Grundy, Kane, Kendall, McHenry, and Will, the land in farms is 87.3 percent of the total land area. Farm water supplies are generally drawn from ground-water sources, including water for domestic use, watering stock, and some for irrigation.

The principal mineral products of the area are sand, gravel, stone, and clay, with small quantities of coal. The value of quarry products in the area in 1956 was $36 million, about half the total value for the state. About 70 percent of the quarry products come from Cook County and the remainder from the other seven counties in the area. Ground water is heavily used in the washing processes in sand and gravel production, and pits and quarries influence the local hydrology.

SOURCE, MOVEMENT, AND OCCURRENCE OF GROUND WATER

The general principles underlying the source, movement, and occurrence of ground water have been described by Meinzer (1923, 1942, p. 385-487) and others. They are summarized here to explain technical terms used in this report.

Ground water is derived from precipitation that falls mainly as rainfall and seeps into the ground. The water infiltrates through loose particles of the soil and percolates downward. Below a certain depth all openings in the earth materials are filled with water. *Ground water* is defined as water in the zone of saturation. The process of addition of water to the ground-water reservoir is called *recharge.*

Openings in which ground-water is stored in the zone of saturation range in size from tiny pores between particles of clay and silt to large crevices in dolomite and limestone. The *porosity* of an earth material refers to its pore space and is expressed quantitatively as the percentage of its total volume.

Earth materials that have interconnected openings large enough to store and transmit water readily into a well or spring are called *aquifers.* The capacity of an earth material to transmit water under pressure is called its *permeability.*

The upper limit of the saturated zone is called the *water table.* The water immediately below the water table is unconfined and can rise or lower freely as water is added or withdrawn. In wells that penetrate the saturated zone under these conditions the water level indicates the elevation of the water table; such wells are called *water-table wells.*

Under natural conditions, the water table roughly parallels the surface topography, rising under the uplands and intersecting the ground surface along perennial streams, lakes, and swamps into which groundwater is discharged by gravity flow from adjacent areas where the water table is higher. The position and shape of the water table may be modified by the kind of rocks present or by other factors affecting permeability. The position of the water table and the discharge of groundwater to streams fluctuate from season to season and year to year.

If a permeable water-bearing formation, or aquifer, is confined between nonpermeable beds and water is supplied to it from a higher elevation, the water is confined under hydraulic pressure. When such an aquifer is penetrated by a well, water will rise above the aquifer in the well to a height equal to the hydraulic head of the aquifier. Ground water that is confined under pressure in this manner is said to be under *artesian conditions.* Wells penetrating such aquifers are called *artesian wells.* If the hydraulic head is above land surface at the well, the well will flow.

To supply a producing well, ground water must move through the aquifers toward the well. Under water-table conditions, pumping lowers the water table in the vicinity of the well and induces the flow of ground water toward the well from adjacent areas. Under artesian conditions, pumping causes, in the vicinity of the well, a reduction of hydrostatic pressure that induces the flow of ground water toward the well. The aquifer under artesian conditions is not dewatered but remains full because the discharged water is derived by the compaction of the aquifer and associated beds, by the expansion of the confined water, and by flow from the recharge area. The compaction of the aquifer and associated beds and expansion of confined water constitute the storage factor of an artesian aquifer.

The depression of the water table, or the reduction of artesian pressure, that results from pumping is in the form of an inverted cone with the well at the center and is called the *cone of depression.*

The measurement of the elevation of the water leve or artesian pressure surface is made by determining th water levels in wells. Two types of water levels ar recognized: nonpumping levels and pumping levels.

The *nonpumping level* is the level at which the wate stands in a well not influenced by pumping in the imme diate vicinity of the well. The level may change ove long periods of time, and also it may be affected b regional pumpage and changes in barometric pressur It is of great importance in evaluating the water resources of a region.

The *pumping level* is the level to which the wate surface lowers in wells during pumping. This level depends on rate and duration of pumping, permeabilit and thickness of the aquifer, and well characteristic

The difference between the nonpumping level and th pumping level in a well is called *drawdown.* The drawdown is a temporary lowering of the water level due pumpage in the well. When the pump is stopped th water level rises. This rise in the water level is calle *recovery.* The yield of a well in gallons per minute p foot of drawdown is the *specific capacity.*

A continued lowering of the nonpumping level of region is called a water level *decline.* Decline of wat level is usually caused by excessive pumpage, diversi of recharge, or drought.

TABLE 3. WELLS TO PRECAMBRIAN ROCKS NEAR THE CHICAGO REGION

		Top of Precambrian			
Name of well	Sec.-T.-R. county	Depth	Sea level elevation	Thickness penetrated	Type of rock
1. Ivan A. Seele No. 1	24-44N-2E Winnebago	2656	−1786	44	Red granite
2. Northern Ill. Oil and Gas Co.*	28-43N-3E Boone	2925	−2105	73	Gray granite
3. Paul Schulte Wyman No. 1*	35-41N-5E DeKalb	3845	−2935	639	Red granite
4. Vickery No. 1 Mathesius	32-35N-1E LaSalle	3532	−2854	24	Granite
5. A. C. Otto No. 1 Swenson	1-35N-5E LaSalle	3700	−3043	24	Granite
6. Larvinger No. 1 Miller	1-36N-4E LaSalle	3469	−2788	190	Granite
7. Ft. Atkinson No. 3 (Wis.)†	9-5N-14E Jefferson	1060	−278		Granite
8. Edgewood Farm Pewaukee (Wis.)†	9-7N-19E Waukesha	1190	−330		Granite

* Grogan, 1950, p. 98.
† Thwaites, 1940, p. 238-239.

GEOLOGY

Unconsolidated deposits of glacial and Recent age, hich overlie the layered bedrock in most of the region igs. 5-6, in pocket) range from a foot or less to more ian 400 feet thick (fig. 12). They are mainly of 'isconsin age, the last major episode of glaciation in ie Midwest, as shown in the classification of Pleisto-ne deposits. Illinoian and possibly older glacial de-sits are preserved beneath the Wisconsin drift at me places.

CLASSIFICATION OF PLEISTOCENE DEPOSITS

Recent stage
Wisconsin (glacial) stage
    Mankato substage
    Cary
    Tazewell
    Iowan
    Farmdale
Sangamon (interglacial)
Illinoian (glacial)
Yarmouth (interglacial)
Kansan (glacial)
Aftonian (interglacial)
Nebraskan (glacial)

The glacial deposits rest on an eroded bedrock sur-e of considerable relief (fig. 13), a surface that was rved primarily by streams before the Pleistocene iciers advanced across the region (fig. 14). The con-uration of the bedrock surface strongly influenced deposition of glacial materials.

Beneath the glacial deposits the bedrock formations, isisting mainly of beds of dolomite (a limestone-like k), shale, and sandstone, dip slightly south of east out 10 feet per mile (fig. 15). In some places the ks are broken and displaced along faults. They are o warped into synclines and anticlines.

The bedrock formations range in age from Precam-an to Pennsylvanian, but rocks below the Silurian in eastern three-quarters of the region are known only from wells (figs. 16 and 17). Silurian age dolomite, which commonly yields ground water from crevices, underlies the drift in most of the region. The oldest rocks encountered directly below the drift are dolomites and sandstones of the Prairie du Chien Series (lower Ordovician) south of the Sandwich fault zone in western Kendall County. The youngest are Pennsylvanian rocks in Grundy and Will Counties.

Bedrock Stratigraphy

The stratigraphy, description and water-yielding characteristics of the rocks in the region are summarized in figure 17. Figure 18 gives the stratigraphic nomenclature used in this report, compared with that of previous reports relating to the Chicago region. Some formations have been grouped or boundaries modified to form what are considered geohydrologic units.

Precambrian Rocks

Rocks of Precambrian age form the basement below the layered sedimentary rocks. No wells are known to have been drilled to the Precambrian rocks in the region of the report, although several have been drilled in adjoining parts of Illinois and Wisconsin. These are listed in Table 3.

The Precambrian rock encountered in most wells in Illinois has been granite or related crystalline rocks. In Wisconsin, wells reaching the Precambrian have encountered granitic rocks or metamorphosed sediments, particularly quartzite. Much of the quartzite appears to stand as "ranges" or "monadnocks" above the general Precambrian level (Thwaites, 1957).

From data on Precambrian depths and Mt. Simon (Cambrian) thicknesses in adjoining Boone, DeKalb, LaSalle, and Kankakee Counties, it appears that the Precambrian surface in the Chicago region slopes eastward and ranges from about 2000 to more than 4000 feet below sea level. Depth to the Precambrian ranges from 3000 to 5000 feet.

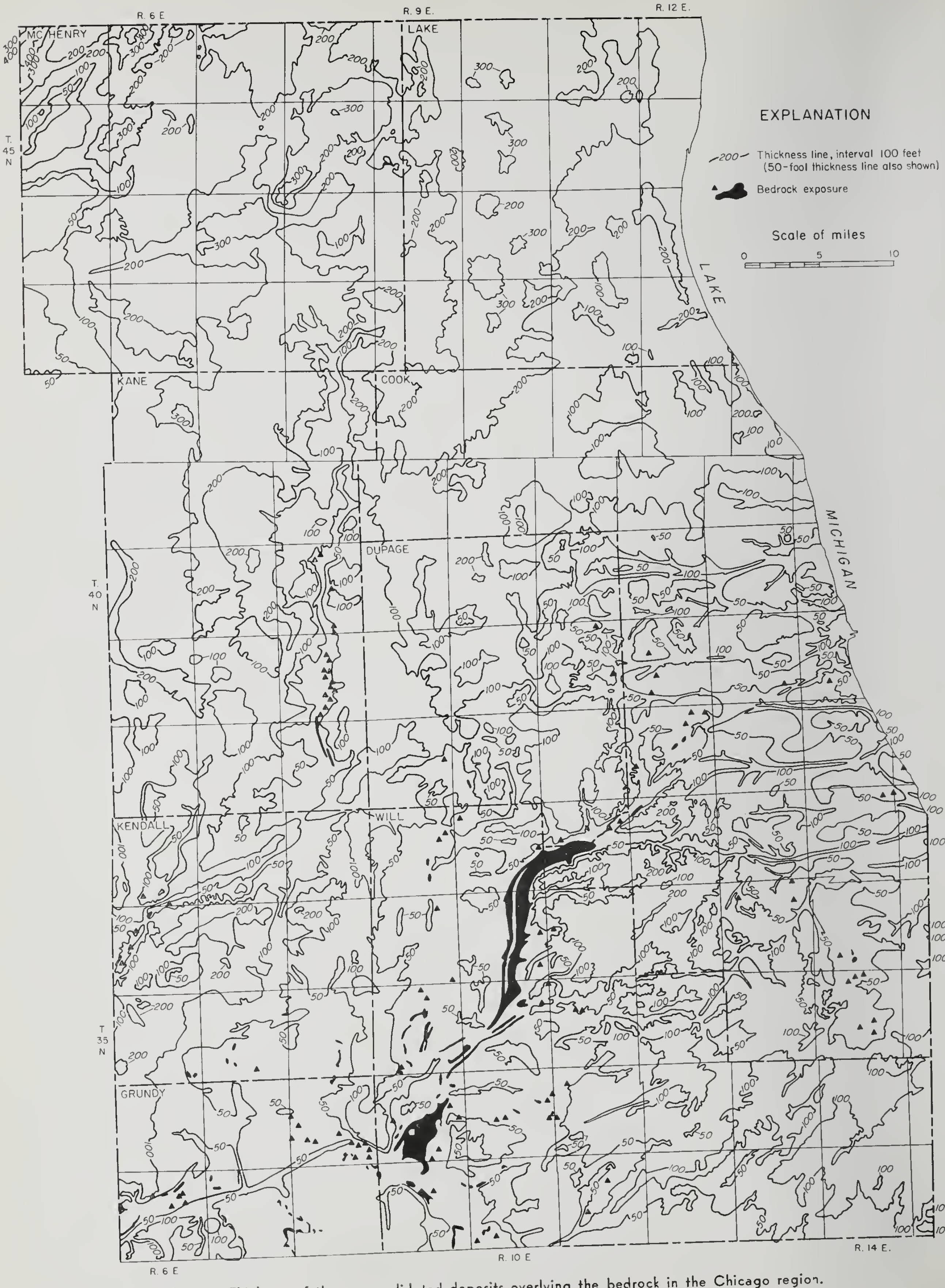


Fig. 12. Thickness of the unconsolidated deposits overlying the bedrock in the Chicago region.

The Precambrian rocks are not sources of ground water but form an impermeable basement complex below the sedimentary rocks.

Cambrian Rocks

The Cambrian rocks (fig. 15) in the area of this report unconformably overlie the Precambrian rocks and are known only from deep wells, none of which penetrate the complete section. These rocks range in thickness from approximatly 2000 feet near the Wisconsin border to more than 3000 feet in Will and Grundy Counties. The lower two-thirds of the Cambrian rocks are generally fine- to coarse-grained sandstones and are overlain by interbedded sandstone, dolomite, and shales, and an upper dolomite.

The Cambrian rocks are divided in this report into five units on the basis of geohydrologic characteristics. The units in ascending order are: 1) Mt. Simon Sandstone and lower sandstone of the Eau Claire Formation; 2) middle and upper members of the Eau Claire Formation; 3) Ironton-Galesville Sandstone; 4) Franconia Formation; and 5) Trempealeau Dolomite.

The Mt. Simon Sandstone and lower incoherent sandstone of the Eau Claire Formation are hydrologically connected and in this report are considered as one unit, called the Mt. Simon Aquifer. The Mt. Simon Sandstone includes the sandstone called Fond du Lac on the state geologic map (1945).

The Mt. Simon Sandstone is fine- to coarse-grained, pink, yellow, and white, incoherent to friable sandstone. In some places it is arkosic and contains red to green shale beds near the base. Granules up to 6 mm in diameter are common in the upper part of the sandstone, and red, micaceous, hematitic shale beds occur at some places in the northern counties. The lower sandstone unit of the Eau Claire Formation may contain a ''sooty'' zone resulting from incrustations of black pyrite on sand grains.

Wells in nearby counties (table 3) indicate that the sandstones of the Mt. Simon and Eau Claire Formations near Wisconsin are approximately 1500 feet thick and hicken southward to approximately 2000 feet. The top of the sandstones (fig. 19) dips from the northwest to he southeast at a rate of 10 feet to the mile. Because of a paucity of information, the structure of the Mt. Simon is not well known. Figure 19 is doubtless a implification of the true structural picture.

The Eau Claire Formation overlies the Mt. Simon Sandstone throughout the region and consists of shale, andstone, and dolomite that grade laterally from one to nother within short distances. The middle and upper parts of the Eau Claire Formation are dolomitic, mi-aceous, fine- to medium-grained, compact sandstone with variable amounts of green to gray, sandy shale and iltstone, and sandy, brown dolomite. Cemented sandtone predominates in the middle unit. Glauconite is ommon throughout the formation.

The Eau Claire Formation is known only from wells hat generally are grouped around the major cities, with the result that regional control for a structure map is uneven. The formation dips from the northwest to the southeast at a rate of about 11 feet to the mile (fig. 20A). The thickness of the middle and upper Eau Claire units is variable. They range in total thickness from less than 300 feet to over 400 feet (fig. 20B).

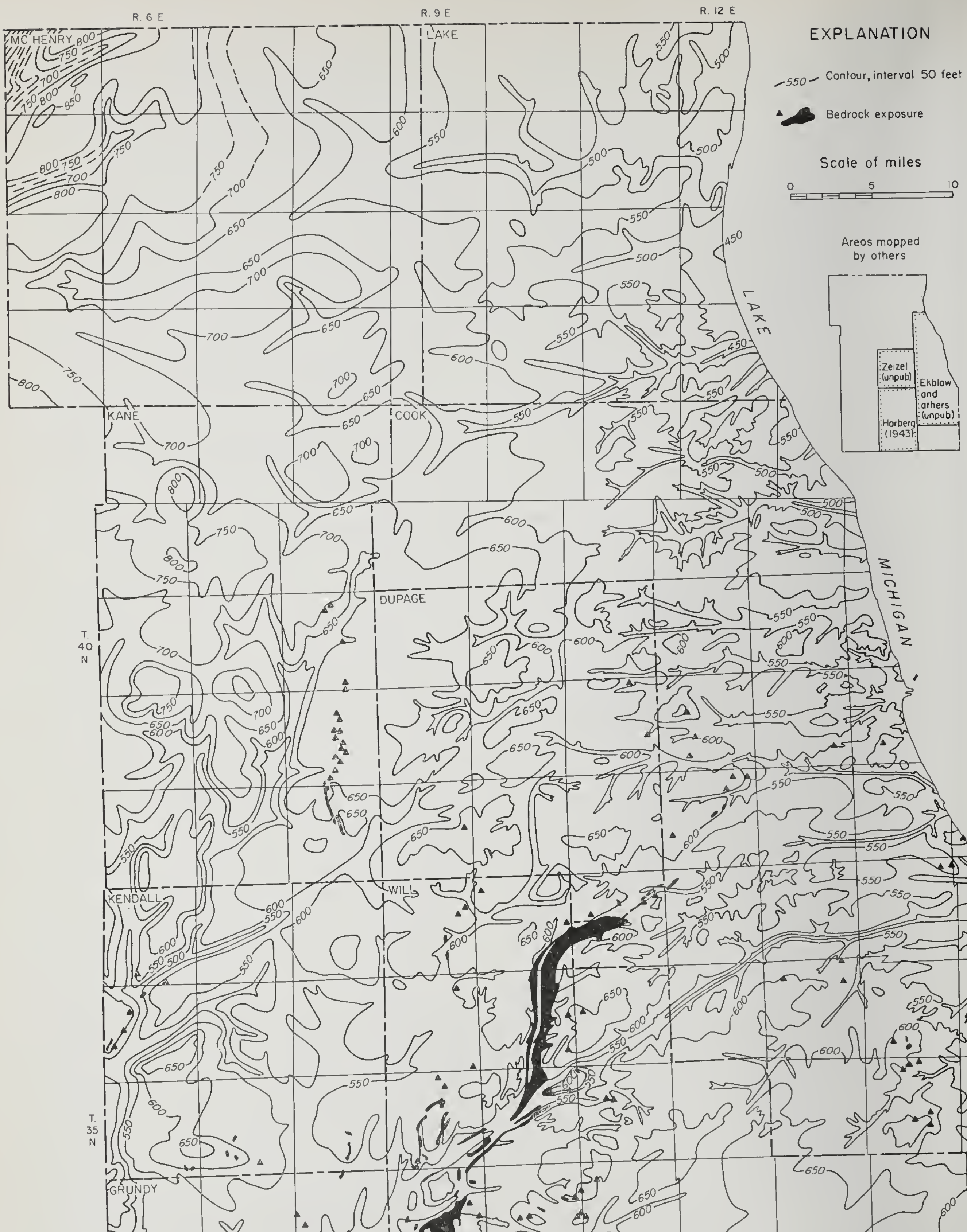
The Ironton-Galesville Sandstone is the major bedrock aquifer in northeastern Illinois. It conformably overlies the Eau Claire Formation and grades upward into the Franconia Formation throughout northern Illinois. The unit is composed of white to light gray, fine- to coarse-grained sandstone, some of which is dolomitic. The dolomite may cement the sandstone or occur as interbedded sandy, pinkish buff lenses. The Ironton-Galesville Sandstone is nonglauconitic except at the top and its compactness varies with the amount of dolomite present as cementing material. The following sample study log illustrates the typical lithology. The well number is based on geographic location and the system is described in the appendix.

Well No. COK 38N12E-18.8g
Suburban Cook County Tuberculosis Sanitarium District,
Well No. 3,
Illinois Geological Survey Sample Set No. 31261.

	Thickness (feet)	*Depth (feet)*
Cambrian System		
Ironton-Galesville Sandstone		
Sandstone, silty, light gray, fine to coarse grains, incoherent; dolomite, sandy, light buff to pinkish buff, very fine, crystalline	31	1400
Sandstone, silty, light buff, coarse to fine grains, incoherent	10	1410
Sandstone, silty, light gray, fine to coarse grains, incoherent; dolomite, sandy, light brown to a pinkish buff, very fine, crystalline	10	1420
Sandstone, silty, light gray, fine to coarse grains, incoherent	40	1460
Sandstone, slightly silty, light gray, medium to fine grains, few coarse grains, incoherent	50	1510
Sandstone, white, fine grains, incoherent to friable	25	1535
Total thickness	166	

All information on the Ironton-Galesville Sandstone in the Chicago region is based on well records. The sandstone dips to the southeast at a rate of about 10 feet to the mile, is generally 175 to 200 feet thick (fig. 21) but thins rapidly to the northeast.

The Franconia Formation is composed of varying amounts of sandstone, shale, and dolomite and is in many ways similar to the Eau Claire Formation. The different rocks grade rapidly from one to another laterally and are commonly interbedded. The sandstone is variegated, dolomitic, fine-grained, compact, micaceous, silty, and grades to buff, pink, greenish gray, finely crystalline, sandy dolomite. The shales are sandy, gray, green, red, micaceous, and weak (caves and slakes


EXPLANATION
550 Contour, interval 50 feet
Bedrock exposure
Scale of miles
0
5
10
Areas mapped by others
Zeizel (unpub)
Horberg (1943)
Ekblaw and others (unpub)
R. 6 E
R. 9 E
R. 12 E
R. 6 E.
R. 10 E.
R 14 E.
T. 45 N
T. 40 N
T. 35 N
MC HENRY
LAKE
KANE
COOK
DUPAGE
KENDALL
WILL
GRUNDY
LAKE MICHIGAN

easily). Throughout the Franconia Formation are large amounts of coarse glauconite that commonly give a greenish tint to the sandstones and shales.

The Franconia Formation underlies the entire region but is known only from wells. It is approximately 100 feet thick and dips from northwest to southeast, as do the underlying formations.

The Trempealeau Dolomite is the uppermost formation of Cambrian age. It grades upward from the underlying Franconia Formation and is commonly slightly sandy and glauconitic at the base. The Trempealeau is buff to gray, very finely crystalline, dense dolomite with minor amounts of geodic quartz and is slightly sandy at the top.

The unconformity that separates the Cambrian and Ordovician rocks occurs at the top of the Trempealeau, causing variation in its thickness. In the northern half of the region the Trempealeau is overlain by the Glenwood-St. Peter Sandstone. The Trempealeau Dolomite has an average thickness of 150 to 200 feet in the region of this report.

Ordovician Rocks

Rocks of Ordovician age in northeastern Illinois are divided in this report into the following geohydrologic units, in ascending order: 1) Prairie du Chien Series, 2) Glenwood-St. Peter Sandstone, 3) Galena-Platteville Dolomite, and 4) Maquoketa Formation (fig. 15). These rocks are predominately carbonate with a middle sand unit (Glenwood-St. Peter) and an upper shale and dolomite unit (Maquoketa). The Ordovician rocks underlie the drift along the western margin of the area (fig. 16) and dip to the southeast. They range in thickness from approximately 500 feet in western McHenry County to more than 1050 feet in southwestern Will County.

The Prairie du Chien Series, consisting of three formations (Oneota Dolomite, New Richmond Sandstone, and Shakopee Dolomite), are considered here as one geohydrologic unit. The series is composed almost entirely of finely to coarsely crystalline, cherty (oolitic), white to light gray to pink dolomite with lenses of sandstone.

The Prairie du Chien rocks are approximately 300 feet thick in southern Will County and thin northward o a feather edge in Cook, DuPage, and Kendall Coun- ies. North of these counties the rocks have been re- noved, except for isolated outliers, by pre-St. Peter rosion. Prairie du Chien rocks underlie the drift in vestern Kendall County southwest of the Sandwich ault zone (fig. 16).

The Glenwood-St. Peter Sandstone underlies all the rea reviewed by this report except extreme western Kendall County (fig. 22). It is white to light gray and uff, fine- to coarse-grained, friable sandstone with vary- ng amounts of silt. Near the top, the sandstone is fine- rained with dispersed coarse grains, dolomitic, with occasional lenses of sandy, green shale and buff to greenish gray, argillaceous dolomite. Most of the Glenwood-St. Peter is a fine- to medium-grained, incoherent to friable sandstone. The sandstone was deposited on a very uneven surface and its thickness varies greatly (figs. 15 and 22B). Where the sandstone is exceptionally thick the lower section may consist of fine- to coarse-grained, pink to reddish brown sandstone with varying amounts of shale, chert, and dolomite fragments. The shale is commonly red or green, sandy, and weak.

Fig. 13. Bedrock topography.

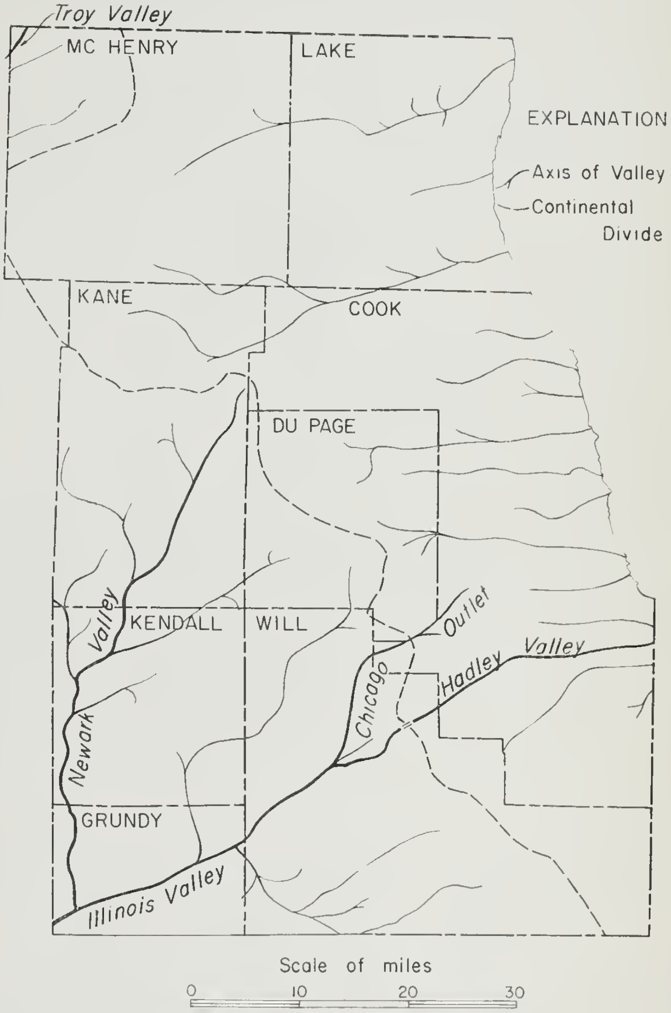


Fig. 14. Bedrock valleys.

The pattern of variation in the thickness of the sandstone (fig. 22B) suggests deposition in previously eroded channels and on adjacent uplands. In some channel areas the Glenwood-St. Peter Sandstone is as much as 650 feet thick. Outside the channel areas, it averages from 150 feet to 250 feet in thickness. The Glenwood-St. Peter Sandstone underlies the drift in only a small part of the area covered by this report and dips generally from the northwest to the southeast at a rate of approximately 10 feet to the mile (figs. 15 and 22A).

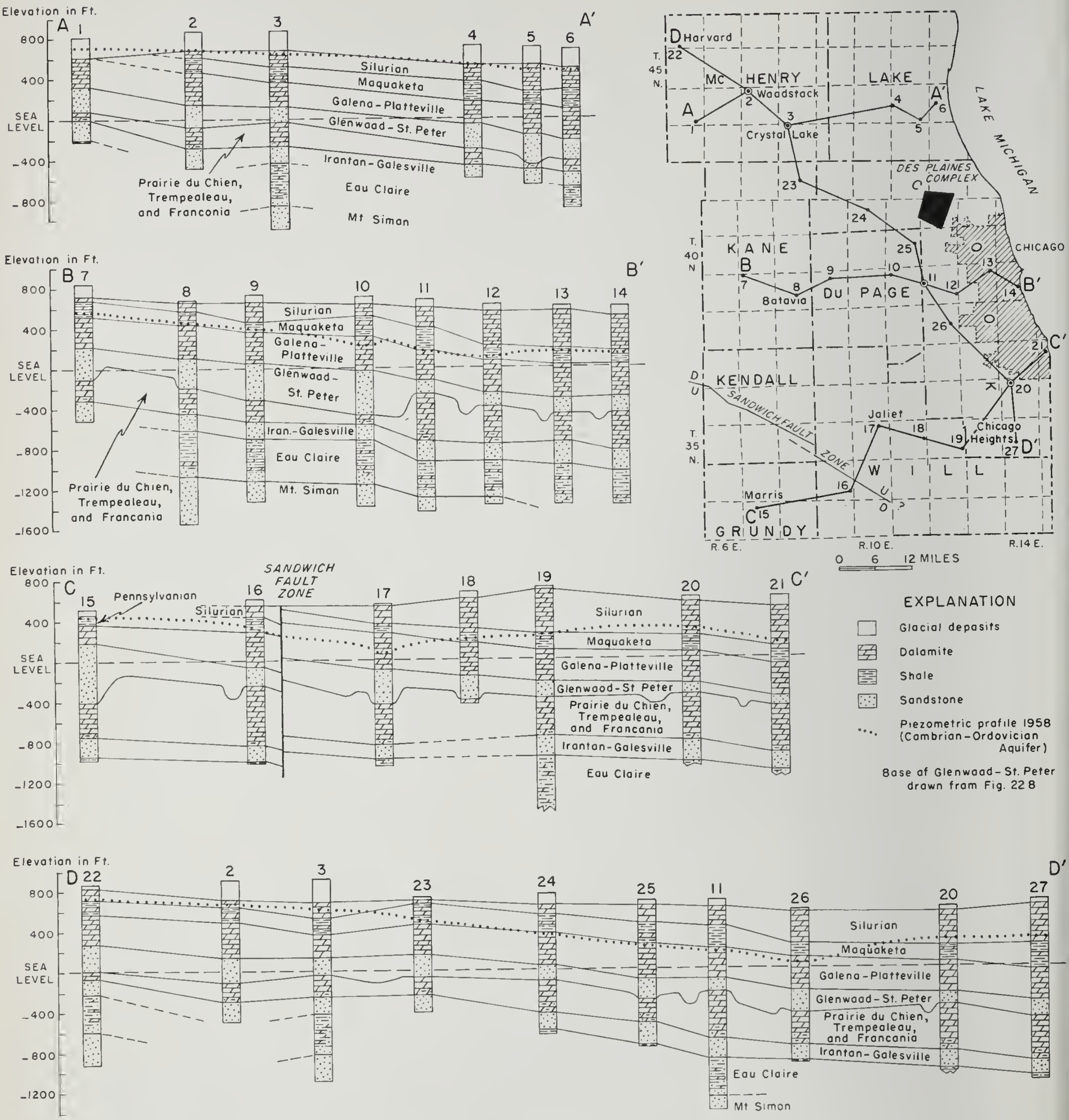


Fig. 15. Cross sections of the structure and stratigraphy of the bedrock and piezometric profiles of the Cambrian-Ordovician Aquifer in the Chicago region.

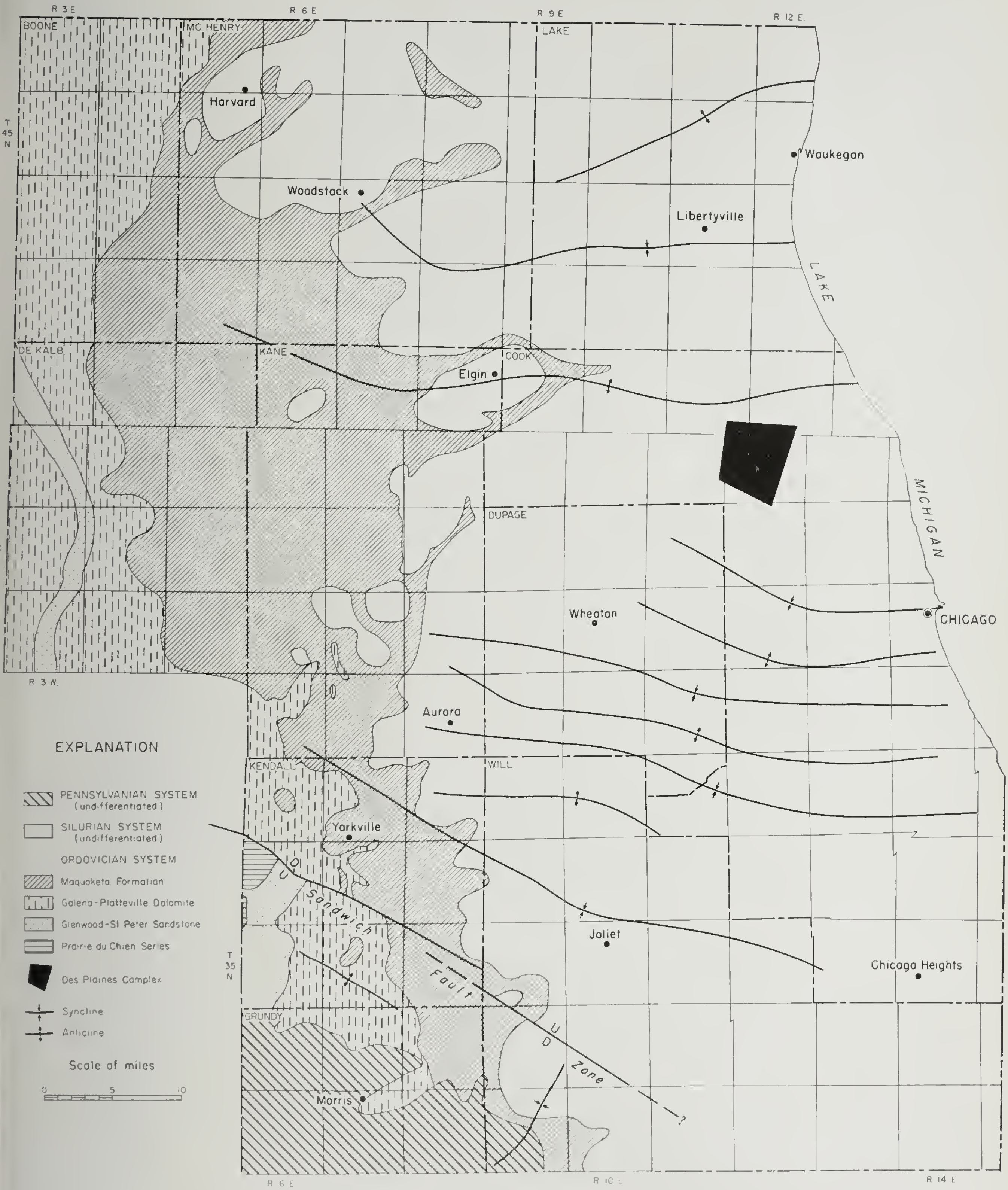
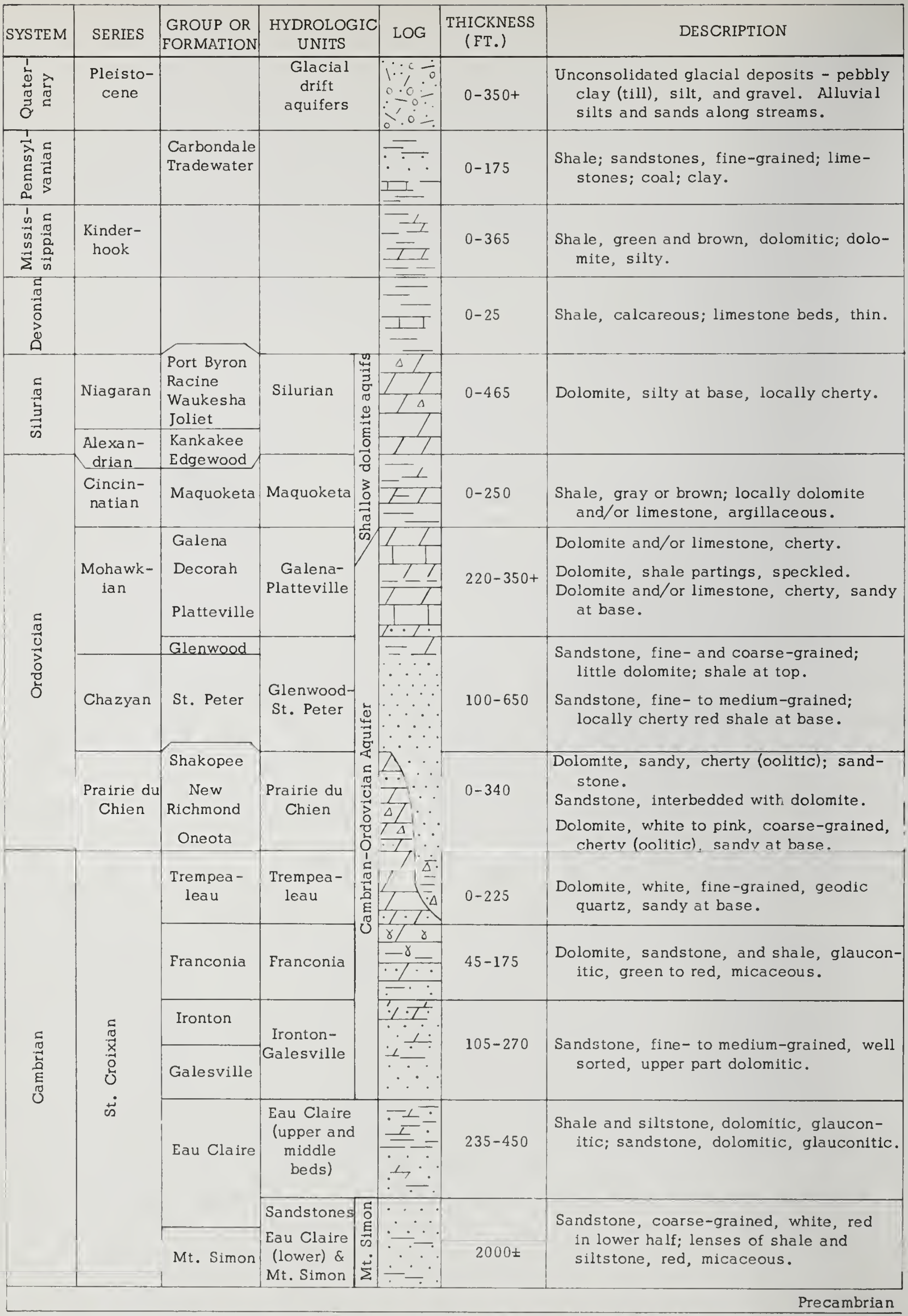


Fig. 16. Areal geology of the bedrock surface and major structures in the Chicago region.



SYSTEM	SERIES	GROUP OR FORMATION	HYDROLOGIC UNITS		LOG	THICKNESS (FT.)	DESCRIPTION
Quaternary	Pleistocene		Glacial drift aquifers			0-350+	Unconsolidated glacial deposits - pebbly clay (till), silt, and gravel. Alluvial silts and sands along streams.
Pennsylvanian		Carbondale Tradewater				0-175	Shale; sandstones, fine-grained; limestones; coal; clay.
Mississippian	Kinderhook					0-365	Shale, green and brown, dolomitic; dolomite, silty.
Devonian						0-25	Shale, calcareous; limestone beds, thin.
Silurian	Niagaran	Port Byron Racine Waukesha Joliet	Silurian	Shallow dolomite aquifs		0-465	Dolomite, silty at base, locally cherty.
	Alexandrian	Kankakee Edgewood					
Ordovician	Cincinnatian	Maquoketa	Maquoketa			0-250	Shale, gray or brown; locally dolomite and/or limestone, argillaceous.
	Mohawkian	Galena	Galena-Platteville			220-350+	Dolomite and/or limestone, cherty.
		Decorah					Dolomite, shale partings, speckled.
		Platteville					Dolomite and/or limestone, cherty, sandy at base.
		Glenwood	Glenwood-St. Peter	Cambrian-Ordovician Aquifer		100-650	Sandstone, fine- and coarse-grained; little dolomite; shale at top.
	Chazyan	St. Peter					Sandstone, fine- to medium-grained; locally cherty red shale at base.
	Prairie du Chien	Shakopee	Prairie du Chien			0-340	Dolomite, sandy, cherty (oolitic); sandstone.
		New Richmond					Sandstone, interbedded with dolomite.
		Oneota					Dolomite, white to pink, coarse-grained, cherty (oolitic), sandy at base.
Cambrian	St. Croixian	Trempealeau	Trempealeau			0-225	Dolomite, white, fine-grained, geodic quartz, sandy at base.
		Franconia	Franconia			45-175	Dolomite, sandstone, and shale, glauconitic, green to red, micaceous.
		Ironton	Ironton-Galesville			105-270	Sandstone, fine- to medium-grained, well sorted, upper part dolomitic.
		Galesville					
		Eau Claire	Eau Claire (upper and middle beds)			235-450	Shale and siltstone, dolomitic, glauconitic; sandstone, dolomitic, glauconitic.
		Mt. Simon	Sandstones Eau Claire (lower) & Mt. Simon	Mt. Simon		2000±	Sandstone, coarse-grained, white, red in lower half; lenses of shale and siltstone, red, micaceous.
Precambrian							

Fig. 17. Stratigraphy and water-yielding properties of the

DRILLING AND CASING CONDITIONS	WATER-YIELDING PROPERTIES	CHEMICAL QUALITY OF WATER	WATER TEMPERATURE °F
Boulders, heaving sand locally; sand and gravel wells usually require screens and development; casing required in wells into bedrock.	Sand and gravel, permeable. Some wells yield more than 1000 gpm. Specific capacities from 2.1 to 66 gpm/ft, av. 12 gpm/ft. Coefficient of trans. from 3400 to 100,000 gpd/ft, av. 25,000 gpd/ft.	McHenry County, hardness from 100 to 450 ppm., av. 275. Other counties, see Silurian below and text.	46° min. 52° av. 54° max.
Shale requires casing.	Jointed beds yield small supplies locally.		
	Limited areal extent; not used as aquifer.		
Upper part usually weathered and broken; extent of crevicing varies widely.	Not consistent; some wells yield more than 1000 gpm. Crevices and solution channels more abundant near surface. Specific capacities from 0.1 to 550 gpm/ft. Highest av. specific capacities (54.4 gpm/ft) in Du Page Co. wells, lowest (5 gpm/ft) in Lake Co. Coefficient of trans. averages 100,000 gpd/ft in Du Page Co., 9000 gpd/ft in Lake Co.	Variable. Hardness, <100 to >1000 ppm. Iron >0.3 ppm in 80% of analyses.	54°
Shale requires casing.	Shales, generally not water yielding, act as barriers between shallow and deep aquifers. Crevices in dolomite yield small amounts of water.		
Crevicing common only where formations underlie drift. Top of Galena usually selected for hole reduction and seating of casing.	Where formation lies below shales, development and yields of crevices are small; where not capped by shales, dolomites are fairly permeable.	Hardness < 100 ppm. H_2S often present.	54° to 55°
Lower cherty shales cave and are usually cased. Friable sand may slough.	Small to moderate quantities of water. Trans. probably about 15% of that of Cam.-Ord. Aquif.	Water similar in quality or slightly harder than that in Ironton-Galesville Sandstone.	53° to 56° 56° to 58° (Lake Co.)
Crevices encountered locally in the dolomite, especially in Trempealeau. Casing not required.	Crevices in dolomite and sandstone generally yield small amounts of water. Trempealeau locally well creviced and partly responsible for exceptionally high yields of several deep wells.		
Amount of cementation variable. Lower part more friable. Sometimes sloughs.	Most productive unit of Cam.-Ord. Aquif; trans. probably about 80% its total. Coefficients of trans. and storage of the Cam.-Ord. Aquif. av. 17,400 gpd/ft and 0.00035.	Hardness 200 to 250 ppm in northwest part of area, increasing toward east and south. Iron usually <0.4 ppm.	56° - 58° to 62° - 64°
Casing not usually necessary. Locally weak shales may require casing.	Shales, generally not water yielding, act as barrier between Ironton-Galesville and Mt. Simon.	Water soft in upper 100'; hardness increases downward (4000 ppm at elev. -2100'); chlorides 400 ppm at elev. -1600', increase at rate of 400 ppm each additional 25' depth.	66° at elev. -1300', increasing 1° with each additional 100' depth. Influenced by water from upper formations.
Casing not required.	Moderate amounts of water; permeability intermediate between that of Glenwood-St. Peter and Ironton-Galesville.		
crystalline rocks			

rocks and character of the ground water in the Chicago region.

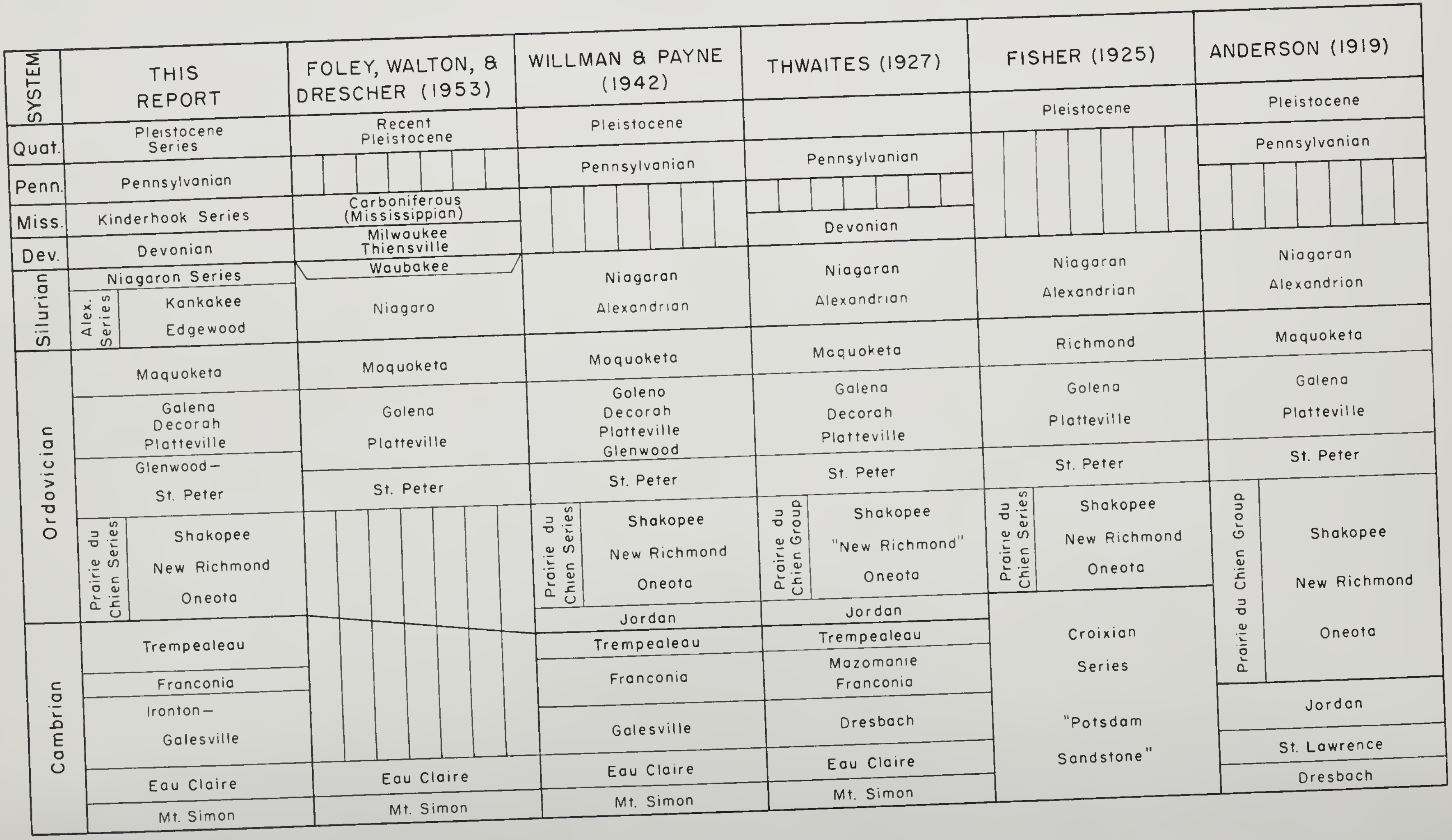

SYSTEM
Quat.
Penn.
Miss.
Dev.
Silurian
Ordovician
Cambrian
THIS REPORT
Pleistocene Series
Pennsylvanian
Kinderhook Series
Devonian
Niagaron Series
Alex. Series
Kankakee
Edgewood
Maquoketa
Galena
Decorah
Platteville
Glenwood—
St. Peter
Prairie du Chien Series
Shakopee
New Richmond
Oneota
Trempealeau
Franconia
Ironton—
Galesville
Eau Claire
Mt. Simon
FOLEY, WALTON, & DRESCHER (1953)
Recent
Pleistocene
Carboniferous (Mississippian)
Milwaukee
Thiensville
Waubakee
Niagaro
Moquoketa
Golena
Platteville
St. Peter
Eau Claire
Mt. Simon
WILLMAN & PAYNE (1942)
Pleistocene
Pennsylvanian
Niagaran
Alexandrian
Moquoketa
Goleno
Decorah
Platteville
Glenwood
St. Peter
Prairie du Chien Series
Shakopee
New Richmond
Oneota
Jordan
Trempealeau
Franconia
Galesville
Eau Claire
Mt. Simon
THWAITES (1927)
Pennsylvanian
Devonian
Niagaran
Alexandrian
Maquoketa
Galena
Decorah
Platteville
St. Peter
Prairie du Chien Group
Shakopee
"New Richmond"
Oneota
Jordan
Trempealeau
Mazomanie
Franconia
Dresbach
Eau Claire
Mt. Simon
FISHER (1925)
Pleistocene
Niagaran
Alexandrian
Richmond
Golena
Platteville
St. Peter
Prairie du Chien Series
Shakopee
New Richmond
Oneota
Croixian
Series
"Potsdam
Sandstone"
ANDERSON (1919)
Pleistocene
Pennsylvanian
Niagaran
Alexandrion
Maquoketa
Galena
Platteville
St. Peter
Prairie du Chien Group
Shakopee
New Richmond
Oneota
Jordan
St. Lawrence
Dresbach

Fig. 18. Stratigraphic nomenclature used in this and previous reports relating to the Chicago region.

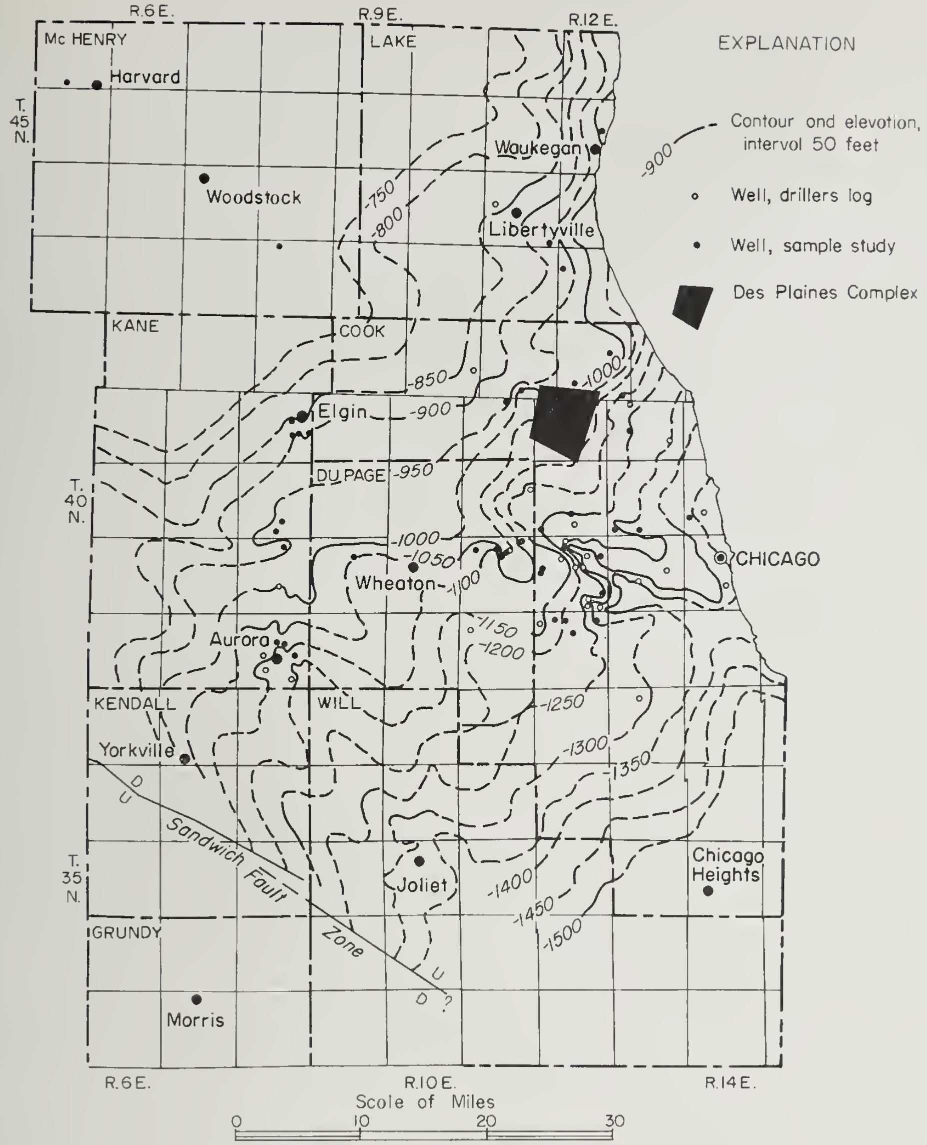


Fig. 19. Elevation of the top of the Mt. Simon Aquifer.

The extreme variability in thickness and lithologic aracter of the Glenwood-St. Peter are exemplified by e following logs of the Automatic Electric Company ells No. 1 and No. 2, which are 770 feet apart:

ll No. COK 40N12E-31.4d
tomatic Electric Company Well No. 1,
inois Geological Survey Sample Set No. 27117

lovician System	*Thickness (feet)*	*Depth (feet)*
lenwood-St. Peter Sandstone		
Sandstone, partly dolomitic, white, fine to medium, few coarse grains	10	800
Sandstone, silty, white, very fine to coarse grains, incoherent	100	900
Sandstone, slightly silty, white, fine to coarse grains, incoherent	60	960
Sandstone, silty, white, very fine to coarse grains	10	970
Total thickness	180	

Well No. COK 40N12E-31.4e
Automatic Electric Company Well No. 2,
Illinois Geological Survey Sample Set No. 27118

Ordovician System	*Thickness (feet)*	*Depth (feet)*
Glenwood-St. Peter Sandstone		
Sandstone, dolomitic, gray, fine and coarse grains	7	790
Sandstone, white, fine to coarse grains .	5	795
Sandstone, partly silty, white, very fine to coarse grains, incoherent . . .	40	835
Sandstone, silty, white, very fine to fine grains, few medium grains, incoherent .	5	840
Sandstone, silty to slightly silty, white, very fine to coarse grains, incoherent .	45	885
Sandstone, partly silty, white, very fine to coarse grains, some siliceous cementing at base	135	1020
Sandstone, white, very fine to coarse grains, incoherent	55	1075
Sandstone, silty at top, pink to light red, very fine to coarse grains, incoherent .	115	1190
Sandstone, silty, very fine to coarse grains, shale, red, green, purple, weak	10	1200
Total thickness	417	

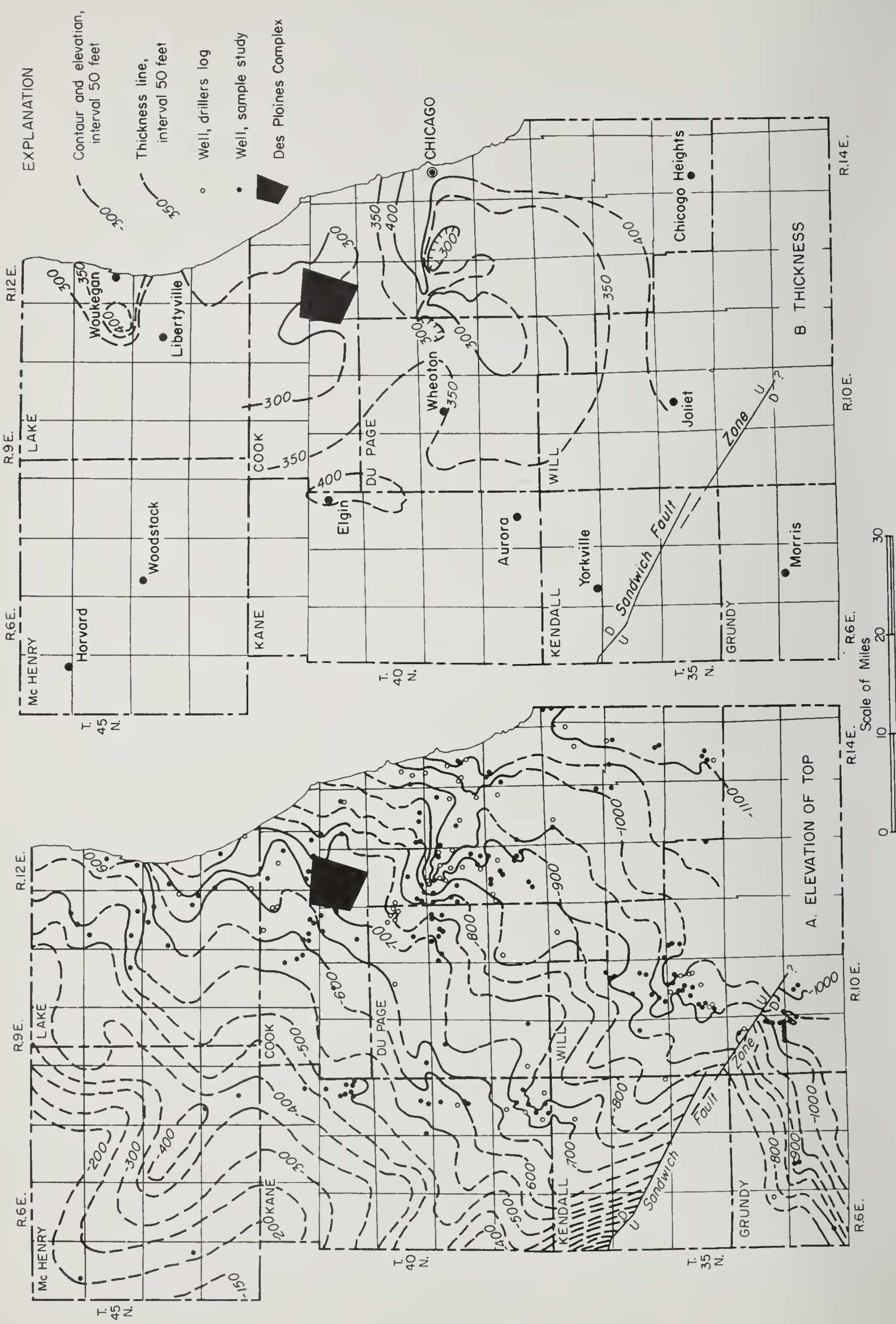


Fig. 20. Elevation of the top (A) and thickness of the upper and middle units (B) of the Eau Claire Formation.

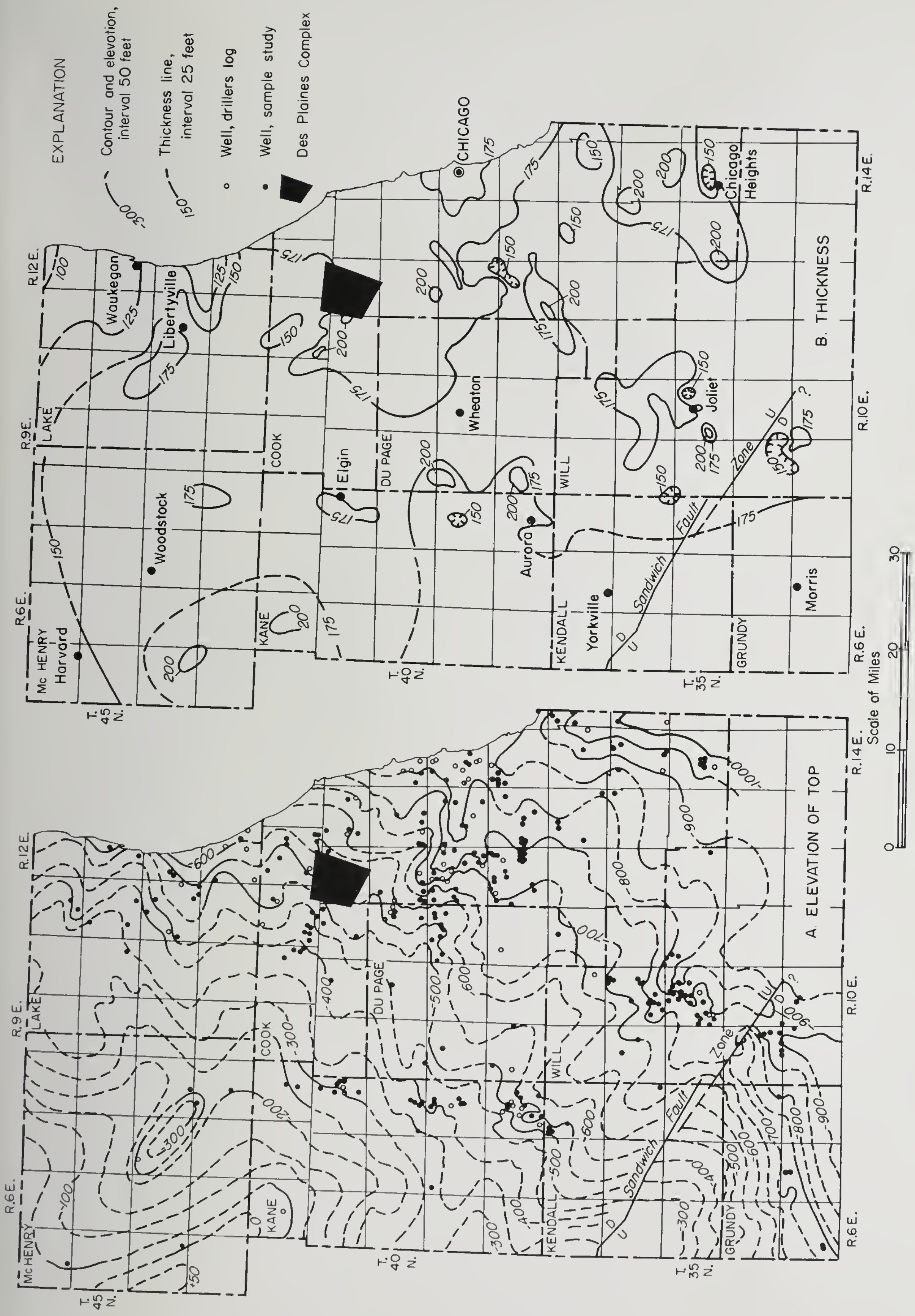


Fig. 21. Elevation of the top (A) and thickness (B) of the Ironton-Galesville Sandstone.

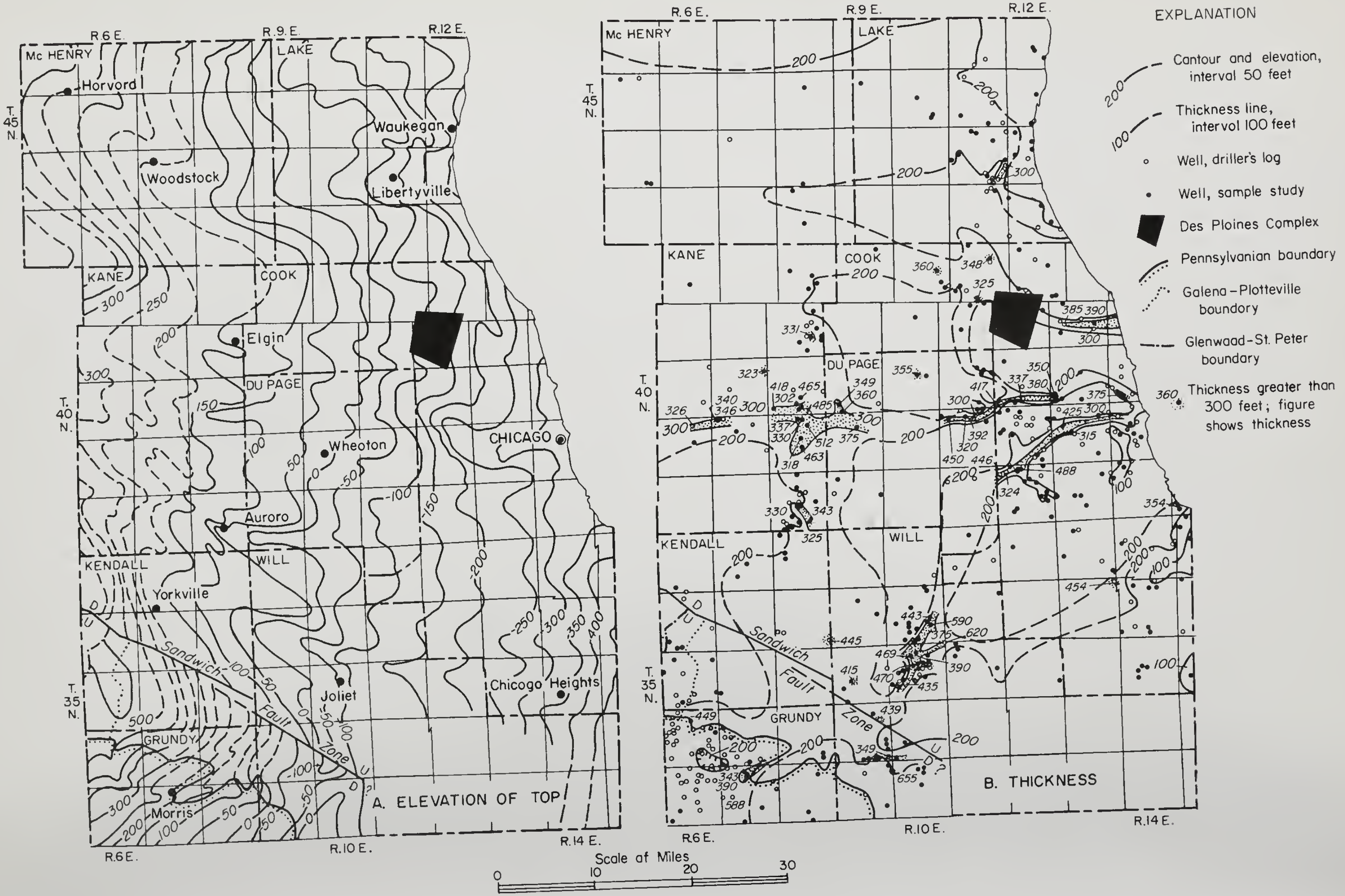


Fig. 22. Elevation of the top (A) and thickness (B) of the Glenwood-St. Peter Sandstone.

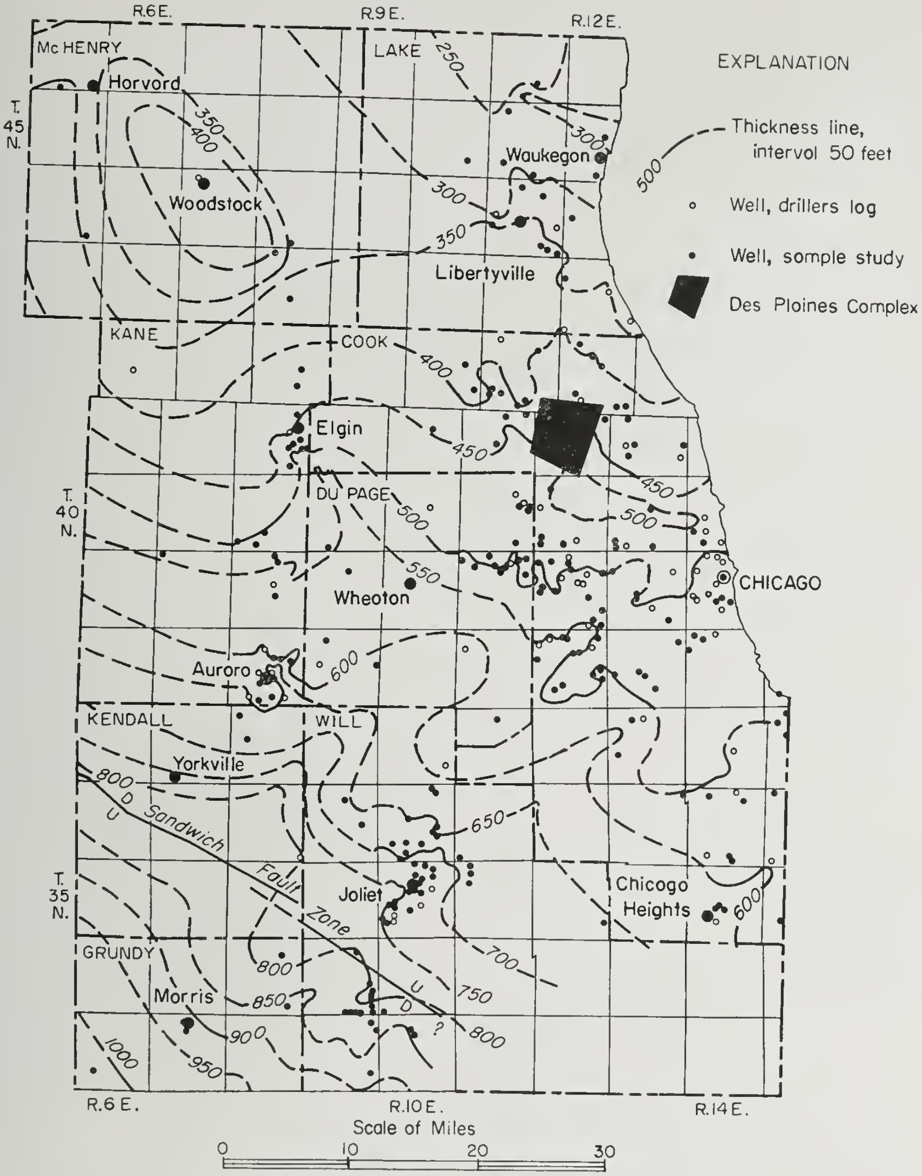


Fig. 23. Thickness of the rocks between the top of the Glenwood-St. Peter Sandstone and the top of the Ironton-Galesville Sandstone.

Considerable thinning of beds between the Glenwood-
. Peter and Ironton-Galesville Sandstones occurs be-
een Grundy and Lake Counties (fig. 23). Much of
e northward thinning was produced by pre-St. Peter
plift and subsequent erosion. Following the erosion
e St. Peter Sandstone was deposited on beds that
nge from Shakopee to Franconia in age.

The Galena-Platteville Dolomite consists of three for-
ations that are considered one geohydrologic unit.
he lowest formation is the Platteville Dolomite, which
commonly argillaceous, cherty in the upper half, buff
gray, very fine- to fine-grained, and commonly mot-
d. Near the base it is sandy. The Decorah Formation
s above the Platteville and consists of fine- to medium-
ained, speckled (red and black) dolomite with thin gray to red shale partings. The overlying Galena Dolomite is cherty in the lower half, fine- to medium-grained, buff to brown, and includes scattered thin shale beds. In Grundy, Kendall, DuPage, southeastern Kane, and western Will Counties the Galena-Platteville is interbedded dolomitic limestone and calcareous dolomite that grade into one another.

The Galena-Platteville Dolomite is uniform in thickness, ranging from approximately 300 to 350 feet (fig. 24B). It dips generally to the east at a rate of about 10 feet to the mile (fig. 24A). Galena-Platteville rocks underlie the drift in northwestern McHenry, southwestern Kane, western Kendall, and northwestern Grundy Counties (fig. 16) and are known from wells in the rest of the region.

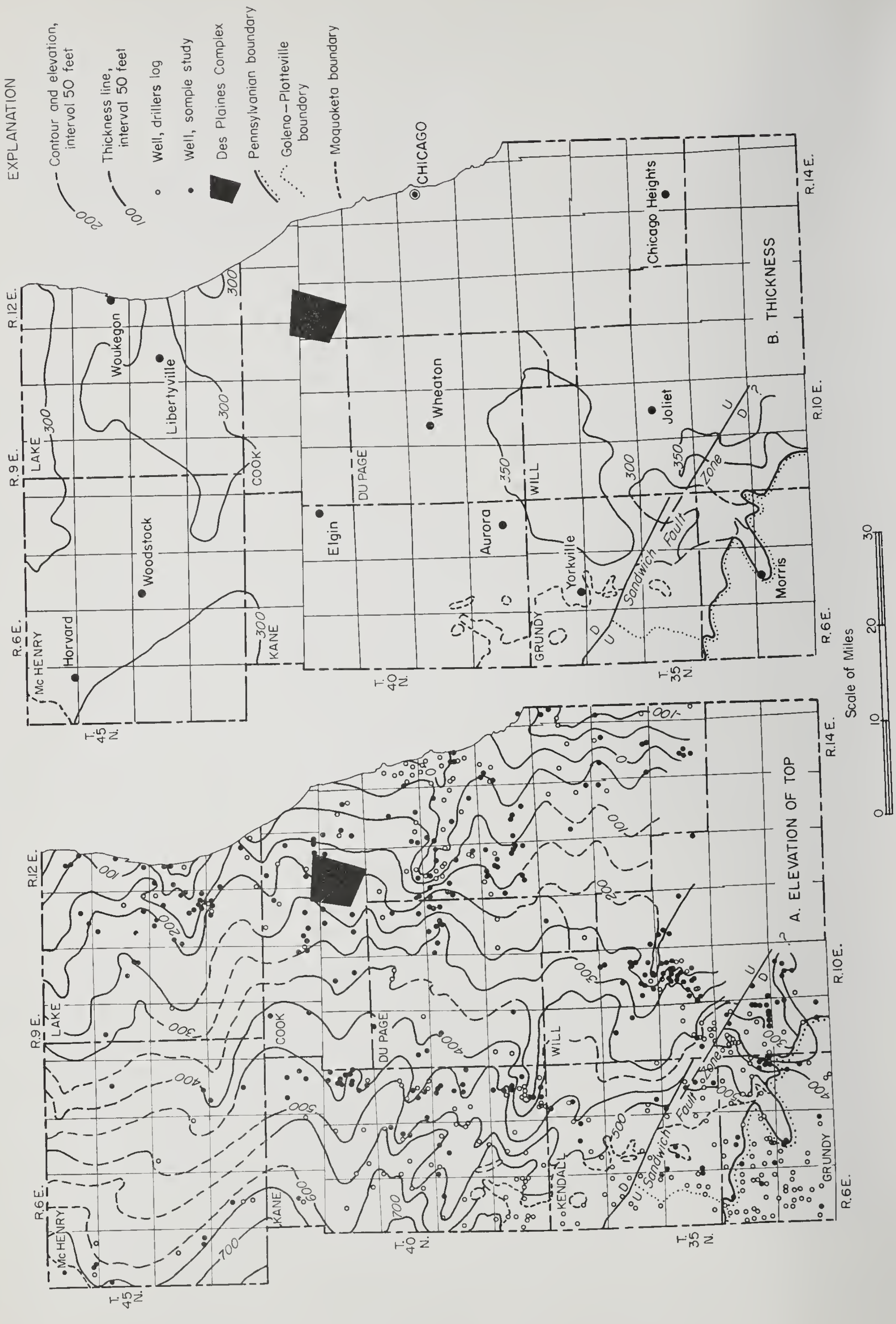


Fig. 24. Elevation of the top (A) and thickness (B) of the Galena-Platteville Dolomite.

The Maquoketa Formation can be divided into three units (fig. 25): 1) lower shale, 2) middle dolomite and/or limestone and shale, and 3) upper dolomitic shale. There is commonly difficulty in separating the middle and upper units that may grade into each other.

The lower unit is normally a brittle, dark brown, occasionally gray or grayish brown, dolomitic shale grading locally to dark brown, argillaceous dolomite. This unit is thicker in Cook and Will Counties where it exceeds 100 feet (fig. 25C). It thins to the north and west to less than 50 feet. Local variations in the thickness of the lower unit may be a result of its grading nto the middle unit.

The middle unit is dominantly brown to gray, fine- to coarse-grained, fossiliferous, argillaceous, speckled dolomite and limestone. It is commonly interbedded with a fossiliferous brownish gray to gray, dolomitic shale. This unit is thicker to the west where it is more than 00 feet locally, and thins to the east (fig. 25B).

The upper unit of the Maquoketa Formation is a greenish gray, weak, silty, dolomitic shale that grades nto very argillaceous, greenish gray to gray dolomite. This dolomite is distinguishable with difficulty from the dolomite of the middle unit or from the overlying dolomite of Silurian age. It ranges in thickness from less han 50 feet in the west to more than 100 feet in parts f Cook and Will Counties (fig. 25A). The three di- isions of the Maquoketa Formation are shown in the ollowing log:

Well No. COK 35N14E-21.3h
alumet Steel Division, Borg Warner Corporation,
Well No. 4, Illinois Geological Survey
ample Set No. 21216

	Thickness (feet)	*Depth (feet)*
rdovician System		
Maquoketa Formation		
Shale, dolomitic, greenish gray, weak; interbedded dolomite, pale yellowish brown to green, fine, silty	80	525
Dolomite, silty, green, light to dark gray, fine to coarse, mottled; few shale streaks in lower half, sandy, olive, weak . .	40	565
Shale, slightly dolomitic, grayish brown to brown, weak to brittle; interbedded thin dolomite, olive, finely crystalline	114	679
Total thickness	234	

The Maquoketa Formation underlies the drift along ost of the western margin of the region and is over- in by the dolomite of Silurian age to the east. It at- ins a thickness of as much as 250 feet and thins to the est (fig. 26B). The formation dips to the east at a te of about 10 feet to the mile (fig. 26A).

urian Rocks

Rocks of Silurian age form the bedrock surface throughout the eastern three-quarters of the region (fig. 16). They are mainly dolomites (popularly called limestones) and are silty at the base. The Silurian rocks are divided into the Alexandrian Series below and the Niagaran Series above (fig. 17). The Alexandrian Series consists of two formations: Edgewood below and Kankakee above.

The Edgewood Formation is an argillaceous to finely sandy, light gray to gray brown, finely crystalline dolomite. At some places it is quite similar to the dolomite of the Maquoketa Formation. The Kankakee Formation is a light gray to buff, cherty, finely crystalline dolomite.

The Niagaran Series is white to light gray, finely to medium crystalline, compact dolomite with varying amounts of silt. White to light gray chert generally occurs in the upper part. At the base the dolomite is commonly green, pink, or red and is slightly silty.

The Silurian rocks are buried beneath glacial deposits except in small areas. They have been deeply eroded during pre-Pleistocene and Pleistocene time, producing variations in thickness (fig. 27). They range from a feather edge to more than 450 feet thick, thickening to the southeast.

Devonian and Mississippian Rocks

Rocks of Devonian and Mississippian age occur locally on top of Silurian rocks in Will and Cook Counties. They are covered by glacial drift and known only from well records.

Rocks of possible Devonian age (fig. 17) are reported in a few drillers' logs. The rocks are generally blue to dark colored, ''limy'' shale.

The Mississippian rocks (fig. 17) are known only from the area of the Des Plaines Complex (fig. 16), where they are dolomitic, gray to brown, weak shales interbedded with silty, slightly cherty, brown to gray, finely crystalline dolomite. They are reported from only a few wells and range in thickness up to 375 feet.

Pennsylvanian Rocks

Rocks of Pennsylvanian age (fig. 17) are the youngest bedrock strata in the region. They are exposed or underlie the glacial drift only in Grundy and southwestern Will Counties (fig. 16) and overlie unconformably the older rocks of the region.

The Pennsylvanian rocks are composed of gray to black, partly calcareous, pyritic, weak to brittle shale; argillaceous, brownish gray, calcareous, pyritic sandstone; gray, argillaceous limestone; and coal. They range in thickness from less than a foot to more than 190 feet in the area of study.

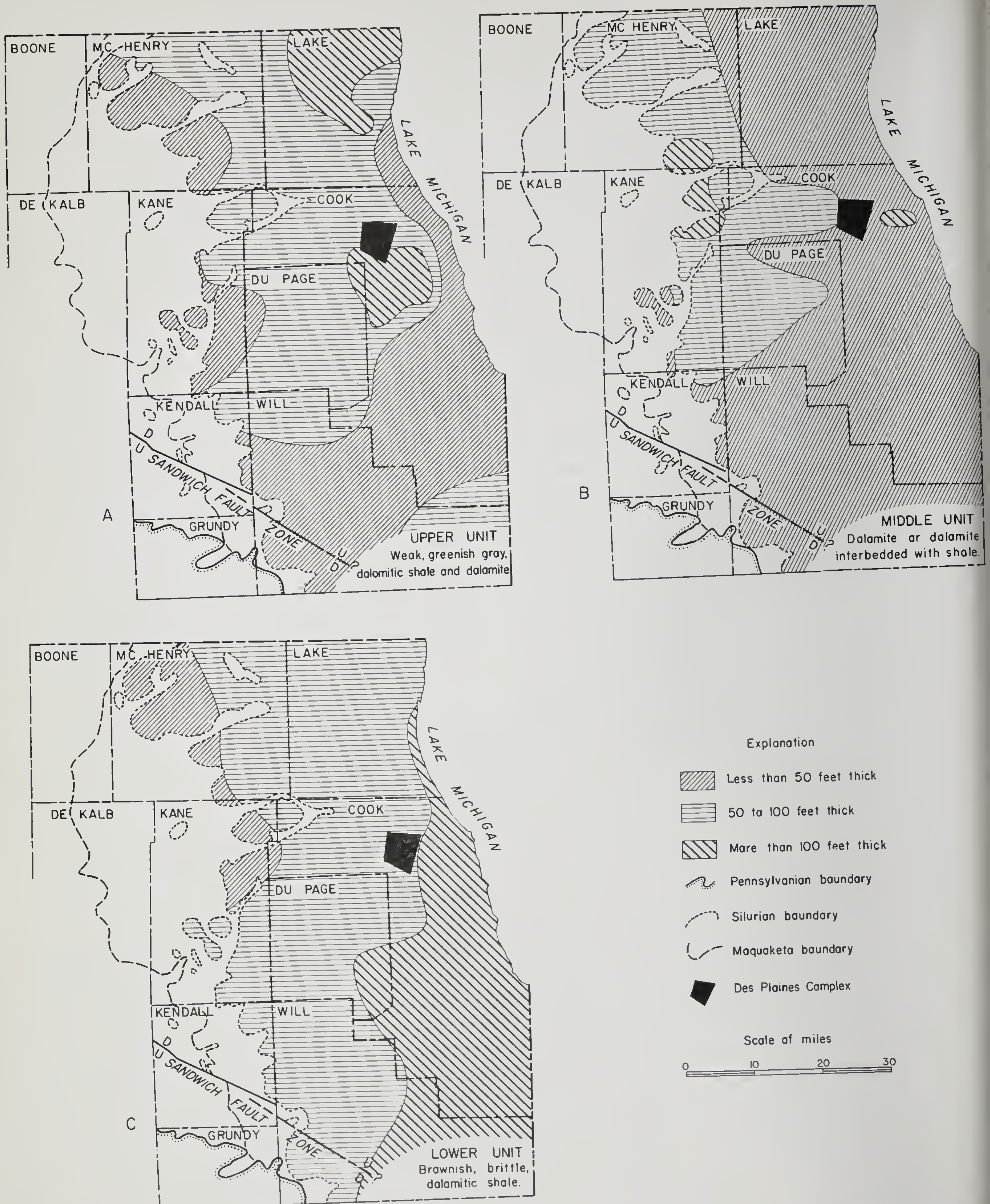


Fig. 25. Lithologic character and thickness of the upper (A), middle (B), and lower (C) units of the Maquoketa Formation.

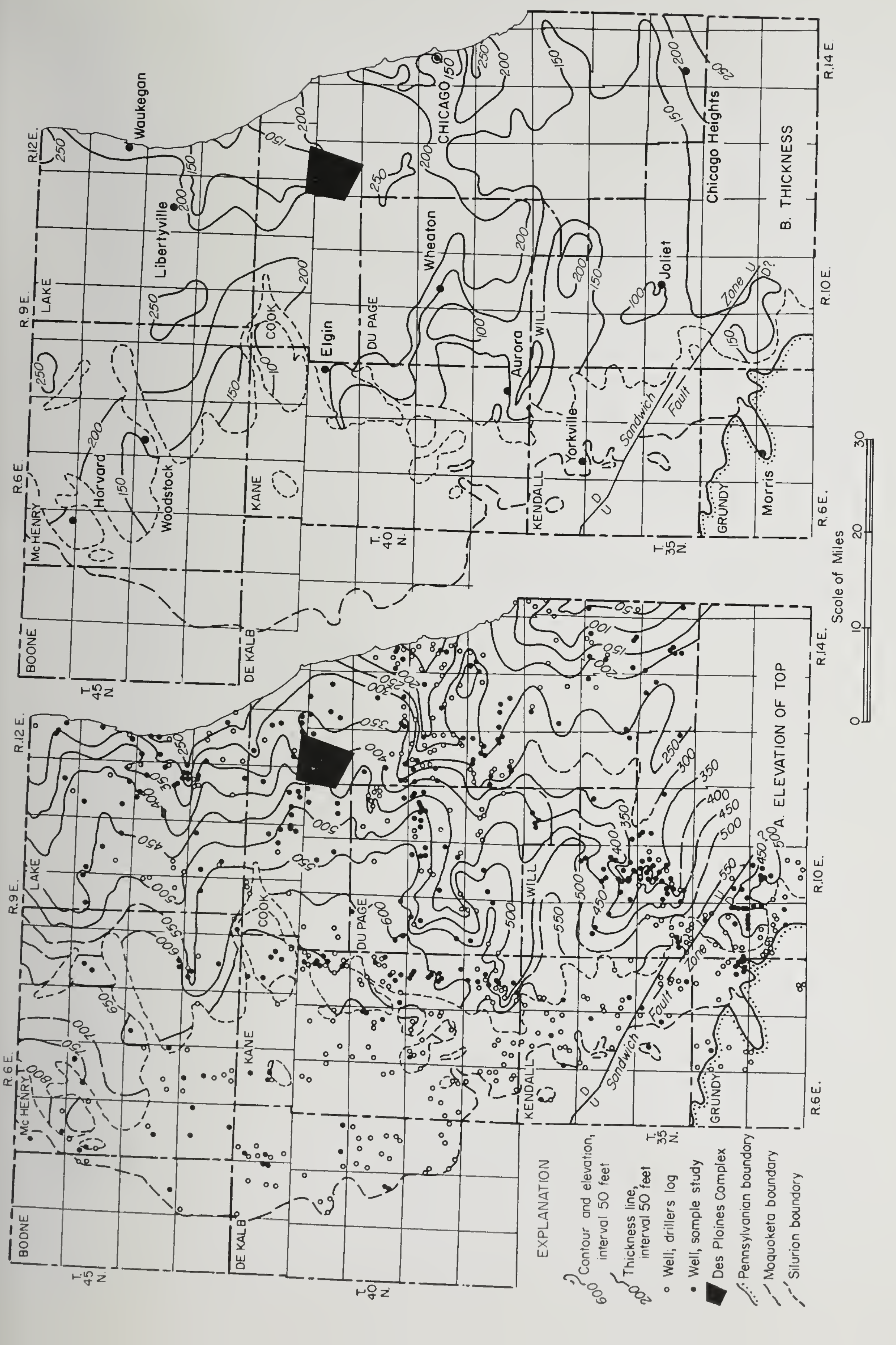


Fig. 26. Elevation of the top (A) and thickness (B) of the Maquoketa Formation. Thickness is not shown where the Maquoketa crops out or directly underlies the glacial drift.

Bedrock Structure

Structure Contour Maps

Structure contours are lines connecting points of equal elevation of a given rock formation. Depth to the formation can be estimated for any location by subtracting the elevation on the structure contour map from the surface elevation at that point. Structure contour maps (figs. 19, 20A, 21A, 22A, 24A, and 26A) show elevations of the tops of the following units: Mt. Simon Aquifer, Eau Claire, Ironton-Galesville, Glenwood-St. Peter, Galena-Platteville, and Maquoketa. Because of the uneven spacing of well control points for the Ironton-Galesville and lower formations, many elevations for the structure maps in figures 19, 20A, and 21A were estimated. Estimates were made of Ironton-Galesville elevations by subtracting from elevations of the Glenwood-St. Peter Sandstone the thickness of the interval from the top of the Glenwood-St. Peter to the top of the Ironton-Galesville (fig. 23). Estimates made in a similar manner were used in constructing the Eau Claire and the Mt. Simon Aquifer structure contour maps.

Regional Structure

Northeastern Illinois is on a structural high called the Kankakee Arch between two major structural basins, the Michigan Basin to the northeast and the Illinois Basin to the south. In the Chicago region the beds have a gentle regional dip to the east and south of about 10 feet to the mile (fig. 15).

Folds

A series of folds trending east-west and pitching eastward with the regional dip are well defined locally by all stratigraphic horizons and appear to be at least post-Silurian in age. The axes of these folds are shown in figure 16.

Faults

The Sandwich Fault zone (figs. 15 and 16) extends eastward from Sandwich, DeKalb County, and into Will County. Faulting is complex. There are at least two major faults with possible minor faults paralleling or at angles to the general trend. In Kendall County a fault in this zone strikes northwest-southeast with the south side upthrown. The throw is more than 50 feet in western Kendall County, but it decreases to the southeast. Farther east in Will County a fault in the same zone strikes northwest-southeast with the north side upthrown and has a throw of more than 125 feet which decreases to the west. The eastern extent of the fault zone is not known due to lack of information in southeastern Will County.

Faulting in the Des Plaines area, Cook County, is complex and has no apparent relationship to regional structure. The 25-square-mile area is bounded and cut by a series of faults. Within the complex, rocks as old as Prairie du Chien occur just below the drift and rocks as young as Mississippian have been preserved. Because of the complexity and lack of data, the Des Plaines Complex is not considered in detail in this report.

History of Bedrock

The bedded sedimentary rocks beneath the glacial drift record the advance and retreat of shallow seas across northeastern Illinois. Sandstones and shales were formed from sands and muds washed into the sea, whereas most dolomites and limestones were formed by deposition of carbonates in clear, shallow seas away from the influx of clastic sediments. Slow general subsidence of the whole area permitted the accumulation of more than 3000 feet of sedimentary rocks, though from time to time episodes of uplift and erosion produced breaks in the sedimentary record. One of the mor prominent episodes of uplift occurred after the deposition of the Prairie du Chien rocks, when erosion beveled rocks ranging in age from Prairie du Chien to Franconia and cut deep channels that were later filled b St. Peter Sandstone.

Final emergence from beneath the sea occurred during Pennsylvanian time when the region lay close t sea level and was successively the site of shallow marin basins and terrestrial coal swamps.

Local deformations of the sedimentary rocks probably occurred during the latter part of the Paleozoi Era. The widespread absence of Paleozoic rocks younge than Silurian in northeastern Illinois makes precise dating of such structures as the Sandwich Fault zone, De Plaines Complex, and local anticlines and syncline highly speculative.

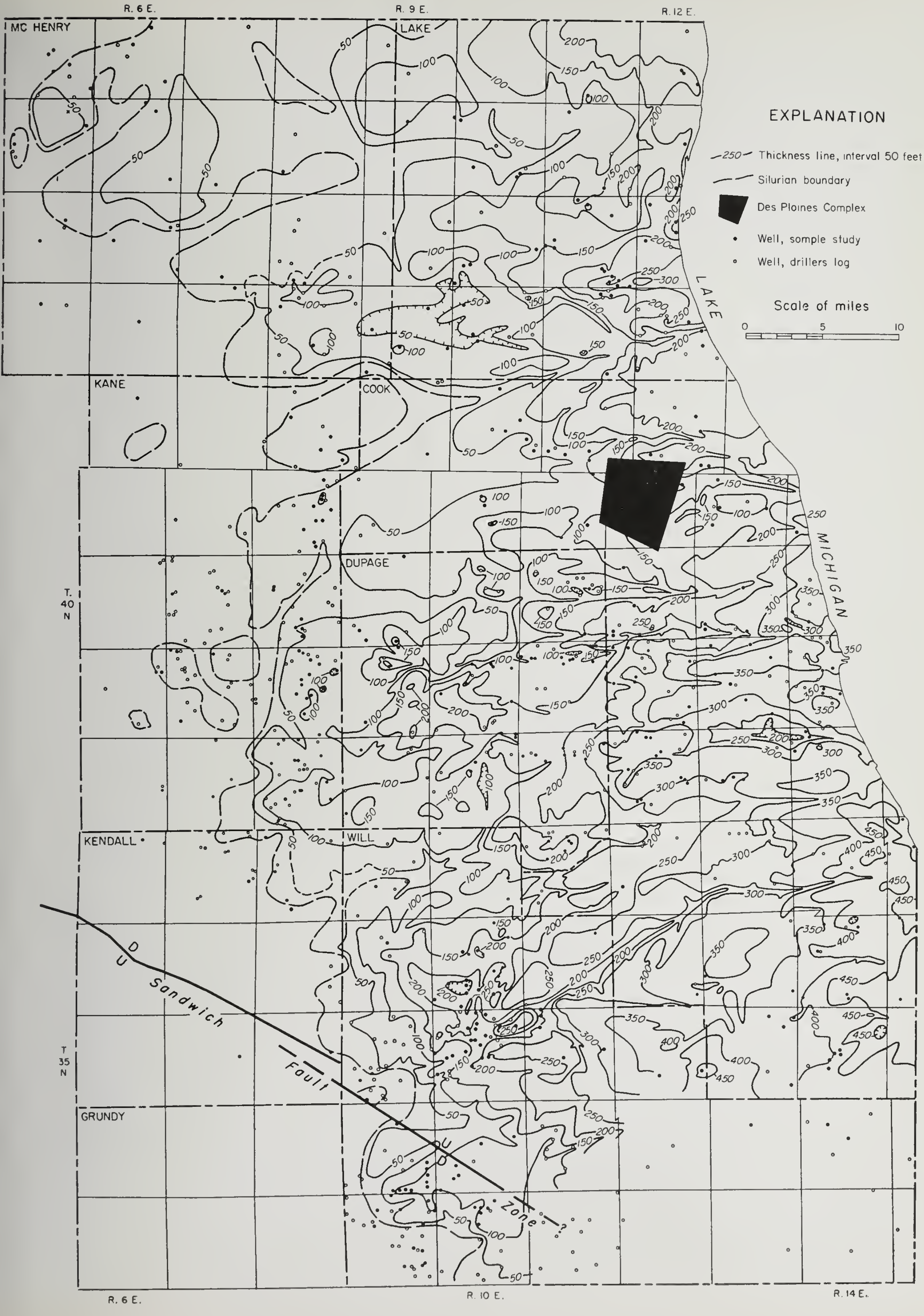
Bedrock Topography

The contouring of the bedrock topography (fig. 13 and the thickness of the unconsolidated deposits (fi 12) is made possible by the hundreds of well record that are available for the region. Most features of th bedrock topography shown in figure 13 have been pr viously delineated, named, and discussed by Horber (1950) in his study of the bedrock topography of t state. Bretz (1955, p. 51-57) also described the bedroc topography of the Chicago region.

The depth to bedrock at any location can be est mated by subtracting the bedrock surface elevati (fig. 13) from the land surface elevation at that poin

The surface of the bedrock topography slopes wi the bedding, descending gradually toward the east. Th is shown by the cross sections of the glacial drift a bedrock (figs. 6 and 15) and the various bedrock stru ture maps. Along the western townships the highe bedrock surfaces rise from slightly more than 650 fe elevation in Kendall County to more than 850 feet McHenry County, whereas much of the bedrock surfa in the eastern half of the region is well below the le of present Lake Michigan (580 feet).

Fig. 27. Thickness of the Silurian rocks.


R. 6 E.
R. 9 E.
R. 12 E.
MC HENRY
LAKE
KANE
COOK
DUPAGE
KENDALL
WILL
GRUNDY
T. 40 N
T 35 N
R. 6 E.
R. 10 E.
R. 14 E.
LAKE MICHIGAN
D
U
Sandwich Fault Zone
U
D
?
EXPLANATION
250 Thickness line, interval 50 feet
Silurian boundary
Des Plaines Complex
Well, sample study
Well, drillers log
Scale of miles
0
5
10
50
100
150
200
250
300
350
400
450

The bedrock surface is scored by a number of stream valleys and their tributaries whose bottom slopes are either directed eastward toward present Lake Michigan, southwestward toward the Illinois-Mississippi drainage system, or southward toward the Mahomet-Mississippi drainage system. Figure 14 shows the axes of the main valleys and the major drainage divide prior to glaciation of the region. The divide, passing from southeastern Will County to northwestern McHenry County, is well west of the present divide developed on the glaciated surface (fig. 4).

Most of the bedrock valleys that slope eastward toward Lake Michigan head near the crest of the Silurian highlands. They are commonly cut less than 100 feet below the adjoining bedrock uplands and pass below the present shore of Lake Michigan at elevations of about 450 feet above sea level.

The valleys west of the divide belong to the Illinois-Newark network or to the Troy-Rock network. Troy Valley, which passes through the northwest township of the region, is cut more than 250 feet below the adjacent upland and is overlain by the thickest glacial deposits in the region (fig. 12). A tributary of the Troy Valley underlies the next township south.

Most of the bedrock valleys of Kendall and southern Kane Counties belong to the Newark system. The main valley heads in the Silurian escarpment in northeastern Kane County and crosses the Maquoketa, Galena-Platteville, Glenwood-St. Peter, and Pennsylvanian rocks. The valley has an average width of a mile and is 100 to 150 feet deep. Before glaciation the Newark drainage continued southward through Grundy and Livingston Counties toward Mahomet Valley, but it was diverted westward, perhaps by Kansan or Nebraskan glaciers. The valleys in western and southern Will, southeastern Kendall, and northeastern Grundy Counties had a similar history.

Two glacial spillways, the Glacial Lake Chicago Outlet and the buried Hadley Valley, breach the bedrock divide in northeastern Will County. Hadley Valley is cut 100 feet or more below the nearby Chicago Outlet (BB, fig. 6, in pocket). The bedrock surface map (fig. 13) suggests that prior to glaciation of the region an eastward flowing stream occupied Hadley Valley east of the divide. A westward flowing tributary of Newark Valley may have headed in the divide west of Hadley Valley. Prior to Illinoian time, glacial meltwaters cut a deep trench through the drainage divide. The Chicago Outlet was cut after Hadley Valley was buried.

Unconsolidated Deposits

The unconsolidated material above the bedrock consists of glacial drift and Recent deposits. The drift is differentiated into that deposited directly from the ice (till) and that modified by the associated melt-water into glaciofluvial (glacial river) and glaciolacustrine (glacial lake) deposits. Recent deposits include those made by wind, running water, standing water, waves, and organisms under present-day conditions.

Glacial Drift

Till is ice-laid debris, a mixture of fragments of all sizes with rarely any stratification. It occurs in the form of marginal morainic ridges and intervening undulatory plains. The marginal moraines record times when the ice front temporarily maintained a fixed position and the intervening plains record times when the ice front melted back.

In composition the tills of the region range from dense clayey silt with few pebbles to gravelly sand containing abundant stratified material. The till of th Valparaiso, Tinley, and Lake Border moraines in Lake Cook, DuPage, and Will Counties (fig. 5, in pocket) ha high clay content and scarcity of pebbles and coarse fragments (Krumbein, 1933, p. 385; Bretz, 1955, p. 43) Clayey till also occurs in Will, Grundy, and Kendall Counties in the Manhattan, Rockdale, Minooka, an Marseilles moraines. The West Chicago moraine of th Valparaiso system, from West Chicago and Elgin northwestward into McHenry County, is composed of sandy gravelly, bouldery till associated with water-laid deposits.

The older moraines west of the Minooka and We Chicago in McHenry and Kane Counties (fig. 5) a highly variable. Some of them are principally claye till; others are less clayey and are associated with muc sand and gravel, and they form rough, irregular topo raphy. Where the Lemont Till east of Joliet is see below the Valparaiso drift—as along Sag Channel a the Des Plaines Valley—it is silty rather than claye and contains abundant stratified material.

Glaciofluvial deposits were laid down by meltwat that was discharged along the front of the ice a through crevasses and channels extending back into t ice. The meltwater contained rock debris ranging fro fine clay and rock flour to gravel, and, in response changing volume and velocity of flow, sorted the pa ticles as it deposited them downstream. Sand and grav generally were deposited close to the ice front or alo channelways that carried a large volume of meltwat The finer particles were carried farther, often not s tling out until they reached the quiet water of a po or lake.

The types and character of glaciofluvial deposits summarized in table 4.

Surficial glaciofluvial deposits are most common McHenry, Kane, Kendall, Grundy, and Will Count They consist mainly of very coarse gravel and sand the form of outwash plains, valley trains, and kames McHenry and Kane Counties and sandy valley tra along the Fox River in Kendall County, along the I nois River in Grundy County and along the Des Plai and Kankakee Rivers in Will County (fig. 5).

TABLE 4. CHARACTERISTICS OF GLACIOFLUVIAL DEPOSITS

ame	Form	Composition and structure
sker	Winding ridge	Sand and gravel, poorly sorted; irregular, arcuate bedding
ame	Hill or knoll	Coarse sand and gravel, poorly sorted; irregular bedding
ame terrace	Knolly ridges or benches along valley sides	Sand and gravel, poorly sorted; bedding distorted along inner wall
utwash plain	Smooth or pitted plain bordering end moraine	Sand and gravel, well sorted; horizontal or cross-bedded
alley train	Terraced valley flat heading in morainal area	Sand and gravel, well sorted; horizontal or cross-bedded

Glaciolacustrine deposits consist of well sorted sand nd gravel accumulated along beaches by wave action, nclined sand and gravel beds laid down in deltas, and ne sediment that settled in quiet waters off shore. They re characteristically found on the Chicago lake plain, ough not restricted to it in the area of the report. The ost extensive and conspicuous deposits of the lake lain are the beach ridges and spits (fig. 5). The prom- ience of some of the beach ridges was increased during acial times by the deposition of wind-blown sand in e form of dunes.

cent Deposits

Much of the deposition of sediments taking place day in the region involves the reworking or redistribu- on of glacial deposits. Silts, sands, and gravels are ifted about by scour and fill in floodplains. Coarse fine sediments are deposited as alluvial fans where ibutary streams of relatively high gradients enter the odplain of a larger stream. Silts are carried by slope ash to lower ground and eventually into ponds, lakes, amps, and streams. Along Lake Michigan waves and ore currents are forming beach deposits. The wind s formed dunes along the lake in Recent time, partic- arly east of the Chicago region in Indiana.

Organic matter is an additional component of Re- nt deposition. Peat, marl, and driftwood are com- n in present-day floodplains. Many swamps in the orly drained morainal areas and on the lake plain with water-loving vegetation and other sediments, rming peat and muck.

ckness

The map of the thickness of the unconsolidated de- sits (fig. 12) shows that the drift is thinner (com- nly less than 50 feet thick) in the low area between Marseilles and Valparaiso moraines (fig. 5) in undy, southeastern Kendall, and southwestern Will unties, and thicker (commonly more than 200 feet ick) in the morainal areas of McHenry, Lake, and ne Counties.

The lines that show thickness of the drift more or s parallel bedrock surface contours in areas of thin drift, but in areas of thick drift they may correspond with either bedrock or surface features. The alignment of thickness lines in the relatively flat Chicago lake plain reflects mainly bedrock valleys and intervening divides at right angles to Lake Michigan. Some of the thickness lines in DuPage, Kendall, Kane, and McHenry Counties outline the higher moraines. More often the thickness lines have irregular patterns because the topographies of the surface and bedrock do not conform and have considerable relief.

History

Between the time the rocks of Pennsylvanian age were formed and the glaciers advanced from centers of snow accumulation in Canada, hundreds of feet of rock were eroded. Prior to the advance of glaciers, the topography of the bedrock was similar to that shown in figure 13. The master stream in the region probably occupied a valley approximately along the axis of Lake Michigan and had as tributaries streams that headed in western McHenry and DuPage Counties.

Pre-Illinoian Pleistocene history is not well recorded in the Chicago region. It is summarized by Bretz (1955, p. 99-132).

The Illinoian ice covered the region and deposited drift that has been identified in wells in McHenry and Kane Counties (Horberg, 1953, p. 26). The Lemont drift, which is exposed east of Joliet and which nearly fills Hadley Valley, may be Illinoian in age (Horberg and Potter, 1955, p. 18). Glacial scour doubtless had created a lake basin in the pre-existing valley along the Lake Michigan axis, and as the Illinoian ice retreated a glacial lake was formed which discharged westward across the area of the Lemont drift.

The Tazewell glacier of Wisconsin age advanced across the region and south and west beyond it to as far as Mattoon and Peoria, and across the Mississippi River near Fulton, Illinois. The Bloomington, Marengo, Elburn, Gilberts, Farm Ridge, and Marseilles moraines were built during successive partial retreats and readvances of the Tazewell glacier.

A great volume of meltwater was discharged by the ice retreating from the Marseilles moraine in the upper part of the Fox River Valley north of Elgin, resulting in the deposition of thick, coarse outwash and the breaching of the Bloomington morainal dam at Peoria.

Following the withdrawal of the ice at the end of Tazewell time, the Fox River and its tributaries cut deep valleys. A new valley was cut across the bedrock divide north of buried Hadley Valley.

The Cary glacier advanced out of the Lake Michigan basin with change in alignment of the ice front to build the Minooka, Manhattan, and Valparaiso moraines. North of Elgin, the Valparaiso ice incorporated abundant coarse material in overriding coarse Marseilles outwash.

Enormous quantities of meltwater were discharged down the Kankakee and Illinois Valleys during the Valparaiso glaciation. The meltwater came from glacial lobes in northeastern Illinois, south-central Michigan, and northern Indiana. Outwash was deposited along the Fox River Valley. In the Kankakee Valley the water constituted a flood with currents that transported large slabs of limestone and built bars of rubble. The volume of water was so great that it could not all escape down the Illinois Valley and therefore rose to form a series of lakes between the younger Tazewell moraines (figs. 5 and 6B-B′). In the lakes, channels were eroded and gravels were deposited by strong currents, silt and sand settled in backwaters, and higher, submerged areas were smoothed by cutting and filling.

After the ice retreated from the position of the Valparaiso moraines, it readvanced and built the slender Tinley moraine as a continuous ridge parallel to the lake basin. With the melting back of the ice from the Tinley moraine, Glacial Lake Chicago formed between the ice front and the moraine. Water that was ponded behind the moraine found an outlet along the already existing Sag and Des Plaines Valleys.

The three beach levels—Glenwood, Calumet, and Toleston (fig. 6B-B′)—correspond to stillstands of the lake. During the Glenwood and Calumet stages stillstands were produced by residual concentrations of boulders from the till (boulder pavements) in the outlet channel; during the Toleston stage further downcutting was checked when the outlet floor had been cut to bedrock. Deepenings of the outlet occurred during times of increased discharge, when outlets to the east were blocked and drainage from glacial lakes in Ontario, southeastern Michigan, and western Ohio was added to that from Lake Chicago.

During the Glenwood stage the ice advanced out of the Lake Michigan basin north of Winnetka to build the four moraines of the Lake Border system.

After retreat of the ice beyond the straits of Mackinac, an eastward outlet into the Atlantic Ocean was established. The lake lowered to the present level of Lake Michigan, and the present Chicago lake plain emerged.

RELATIONSHIP OF GEOLOGY TO GROUND WATER

General Relations

The source, occurrence, movement, quality, and availability of ground water are controlled by the nature, distribution, and structure of the various earth materials below the land surface. Of prime importance is the occurrence of permeable formations that serve as aquifers, storing ground water, channelling the movement, and acting as avenues of recharge.

The nature of the permeable formations has hydrologic significance because it affects water quality, rate of yield, and design of wells. Relatively impermeable beds such as shales act as barriers to ground-water movement or maintain pressure differences between aquifers and sometimes require special handling during drilling or well construction. Geologic structure commonly influences the direction of ground-water movement, artesian pressures, water quality and temperature, and areas of recharge. A study of the geologic history, particularly episodes of uplift, weathering, and erosion, sometimes explains the occurrence of zones o porosity, permeability, or cementation.

Cambrian-Ordovician and Mt. Simon Aquifers

The Mt. Simon Aquifer, previously defined, is th lowest known hydrologic system of the area. It is sep arated from the overlying system by the middle an upper parts of the Eau Claire Formation.

Above the Eau Claire occurs a sequence of rocks hy drologically interconnected and referred to in this r port as the Cambrian-Ordovician Aquifer. It consist in upward order of the Ironton-Galesville Sandston Franconia Formation, Trempealeau Dolomite, Prairi du Chien Series, Glenwood-St. Peter Sandstone, an Galena-Platteville Dolomite. This interconnected hydr logical system is, in most of the area, separated from t overlying aquifers by the Maquoketa Formation. I general, the principal water-yielding units are the san stones of the Ironton-Galesville and Glenwood-St. Pete

Many of the deep bedrock wells in this region a not limited to a single aquifer but are open to the M Simon Aquifer as well as the Cambrian-Ordovici Aquifer, and even to the Silurian age dolomite abo the Maquoketa Formation.

The various units, as they are encountered in drilli wells, are described below.

Galena-Platteville Dolomite

The Galena-Platteville Dolomite yields small quan ties of water from joints, fissures, and solution caviti Yields are greater in the western part of the regi where the dolomite directly underlies the drift and weathered. Finely disseminated pyrite in the rock responsible for dark, sulfurous water in many wel Occasionally oil shows are encountered. Because t dolomite is firm, homogeneous rock of uniform thi ness (fig. 24B) it is easily recognized during drilli and is a favorable unit in which to seat casing.

Glenwood-St. Peter Sandstone

The variability of the Glenwood-St. Peter Sandst in texture, cementation, and thickness creates anomal in water-yielding capacity and problems in drilling a well construction. The upper part generally is not p ductive because of the shaly or dolomitic character the sandstone. The basal part, composed of shale a conglomerate, sometimes called by drillers the " Peter caving zone," also is unproductive. Thus grou water production from the Glenwood-St. Peter gener is restricted to 60 to 80 feet of sandstone that occurs to 200 feet below the top of the formation.

The occurrence of unusual thicknesses of Glenwood-St. Peter in channel areas (fig. 22B) may result in reater yields where the sand is clean. Often, however, he thickening in the channel areas is a result of thickning of the lower shale or rubble zone, which does not eadily yield water. Water in the lower part of the Glenvood-St. Peter in the channel areas may be slightly nore highly mineralized because it circulates poorly in he less permeable part of the sandstone.

The Glenwood-St. Peter presents some difficulties in rilling and well construction because the friable sands end to slough off and the lower shale and rubble zone ends to cave. It is common practice to set a liner hrough the lower part of the formation.

rairie du Chien Series

The Shakopee and Oneota Dolomites are not well reviced and yield little ground water. The New Richiond Sandstone no doubt furnishes some ground water ı deep rock wells, but its variation in dolomite cont and thickness makes it unpredictable as a groundater source.

empealeau Dolomite

The presence of water-yielding crevices in the upper art of the Trempealeau Dolomite in some wells is reorted by drilling contractors and is indicated in a few aliper logs of deep wells. Crevicing may be related the unconformity between the Trempealeau and rairie du Chien Series or, in the northern half of the gion, between the Trempealeau and Glenwood-St. eter Sandstone. Filling of the fissure systems has ocırred locally. Where unusually high specific capacies of deep rock wells are obtained it is likely that cavies in the Trempealeau provide substantial quantities water.

anconia Formation

Although the shales and dolomites of the Franconia do ot readily yield water, the sandy portion of the formaon is permeable and probably contributes some water deep rock wells where it is not cased off by liners.

nton-Galesville Sandstone

The Ironton-Galesville Sandstone is the most constently permeable and productive aquifer in northstern Illinois. Although the lower 20 to 85 feet of the ndstone is commonly the least cemented and most pereable part of the interval, clean friable zones also are countered in its upper dolomitic part in some wells. cause the most favorable water-producing zone ocrs in the lower part of the unit, it is advisable to netrate the full thickness of the Ironton-Galesville if aximum well yield is desired. In fact, drilling to a ort distance below the base of the Ironton-Galesville advisable so that caving in the well will not shut off e lower productive section.

The poor cementation of the sandstone is responsible r some of the caving and sand-pumping problems in deep wells. Study of cuttings and caliper logging can sometimes lead to identification of cemented and weak zones and thereby guide shooting and rehabilitation of wells.

Eau Claire Formation

The middle and upper parts of the Eau Claire Formation in the Chicago region are primarily shale, dolomitic sandstone, and dolomite and are, therefore, not a productive part of the deep aquifers. However, the unit is of hydrologic importance in that it is a barrier between the Ironton-Galesville Sandstone and Mt. Simon Aquifer which contain water of different quality and head. The shales of the Eau Claire Formation protect the Ironton-Galesville from the intrusion of highly mineralized water from the Mt. Simon Aquifer. The effectiveness of this barrier under various pressures needs further study.

Mt. Simon Aquifer

The coarse, clean portions of the Mt. Simon Aquifer are capable of yielding moderate quantities of water. However, the erratic distribution of the clean beds, the occurrence of micaceous shales and siltstones, and the presence of warmer, more highly mineralized water make the Mt. Simon a less consistently favorable aquifer than the Ironton-Galesville. Wells that withdraw water from the Mt. Simon Aquifer at an elevation of 1300 feet or more below sea level commonly yield water too salty for ordinary use.

Maquoketa Formation

The Maquoketa Formation is at least a partial barrier between the shallow ground water of the drift and Silurian age dolomite above and the deeper ground water of the Cambrian-Ordovician Aquifer. The lower dense shale unit of the Maquoketa Formation is the most persistent and doubtless the most impermeable unit (fig. 25C). The effectiveness of the Maquoketa as a barrier is indicated by the reduction in crevicing and water-yielding capacity of the Galena-Platteville Dolomite where the Maquoketa overlies it (fig. 16). This is also suggested by studies by Foley and Smith (1954, p. 228) of recharge of the deep sandstone aquifer.

Dolomite beds in the middle unit of the formation yield small quantities of ground water. These beds are best developed in Kane County.

The Maquoketa is subject to swelling and caving and is customarily cased in deep rock wells.

Shallow Dolomite Aquifers

Ground water in the shallow dolomite occurs in joints, fissures, and solution cavities, so yields at any given location generally are unpredictable. The reservoir capacity of the rock as a rule is controlled more by solution openings below the weathered bedrock surface than by stratigraphic position. The development of solution openings has been controlled by fracture and bedding planes near the surface and by regional dips.

About 75 percent of the dolomite wells in a selected 17-township area in southern Cook and Will Counties are completed within the upper 75 feet of the rock (fig. 41).

Because the openings occur mainly in the upper part of the rock it is likely that there is good connection with the overlying glacial drift.

In the circulation of ground water in other limestone terrains, concentration of flow and greater velocities near the points of discharge along drainage lines result in the enlargement of channels. If in the northeast region of Illinois the bedrock valleys were lines of discharge during the development of solution openings, they should be bordered by areas of high permeability and consequently high productivity. Available production figures are inadequate to test this hypothesis.

There is, however, an additional reason why higher yields may be anticipated in the areas underlying and adjoining bedrock valleys. As openings in the dolomite are connected with porous zones in the drift, it follows that where creviced dolomite is overlain by water-bearing sand and gravel deposits there will be more immediate recharge of the dolomite aquifer than in areas where glacial till rests on the bedrock.

Production records and drillers reports indicate that in some generally definable areas in the region crevicing is extensive and high yields can be obtained, and in other areas the dolomite is generally dense and ''tight.'' DuPage County and eastward to the Des Plaines River south of LaGrange is one such favorable area, whereas a 2- to 8-mile belt along Lake Michigan is generally unfavorable.

Among the factors that may be responsible for differences in ground water productivity of the dolomite in various areas in northeastern Illinois are:

1. Differences in development of solution zones with respect to bedrock topography.
2. Differences in depth of ground water circulation and therefore depth of solution. For example, shallow impermeable shales in a given limestone area may limit solutional downcutting and promote extensive enlargement channels in the soluble rock above.
3. Differences in permeability of the overlying drift.
4. Differences in solubility of the various dolomite units.

Glacial Drift Aquifers

Ground water in the drift is obtained mainly from sands and gravels that occur as surficial deposits or, more commonly, as deposits underlying or interbedded with glacial till. Because of their irregularity of occurrence, glacial drift aquifers are more difficult to locate than bedrock aquifers. The difficulties are compensated for in part by lower costs of drilling and pumping, often by water that is cooler or of better quality, and at som places by greater yields.

Surficial sand and gravel deposits are fairly wide spread in Kane, McHenry, and western Lake Counties Esker and kame deposits, restricted in areal extent an standing above the surrounding countryside where the are often excavated for gravel operations, are of limite importance as sources of ground water. In contras deposits of outwash plains and valley trains, being mor extensive and occurring in lowlands where they ar likely to be below the water table, are of considerabl importance.

Large supplies of ground water are often encountere in sand and gravel at the base of the drift, directly abo bedrock. The chances of penetrating continuous wate bearing beds of considerable thickness are better withi the bedrock valleys than in bedrock uplands because 1 the drift is thicker above bedrock valleys, increasing th probability of encountering sand and gravel, and 2 meltwaters were concentrated in valleys during glaci stages, locally resulting in the deposition of sorted d posits. The bedrock valleys that slope eastward towa Lake Michigan and up which the glaciers advanced, a generally filled with till or with fine sediments of sla water origin.

Buried sand and gravel deposits commonly occur ne the outer margin of end moraines. Here the wat bearing deposits are often found at the boundary b tween till sheets and may be continuous over wide are Drift aquifers in areas between the moraines are co monly lenticular and discontinuous.

Favorable Localities

Favorable areas for sand and gravel aquifers, as terpreted from surficial geology, well records, and ear resistivity surveys, include the following:

Surficial outwash plains and valley trains (figs. 2 a 5)

1. Lowland of Rush Creek and Piscasaw Creek V leys west of Harvard.
2. Valleys of Kishwaukee River and North a South Branches west of Woodstock and Crys Lake.
3. Nippersink Creek lowland west and south Hebron.
4. Coon Creek lowland northwest of Hampshire.
5. West Chicago outwash between Naperville a Elgin and along the Fox River Valley south Elgin.
6. Des Plaines River Valley north of River For
7. DuPage River Valley south of Wheaton a Naperville.
8. Des Plaines and DuPage River Valleys in vici of Joliet and Plainfield.

Glacial fill in buried bedrock valleys (figs. 6 and 17)

1. Troy Valley.
2. Newark Valley.
3. Hadley Valley.

Buried sand and gravel deposits of various origins (figs. 2, 5, and 6)

1. Lemont drift of Joliet, Orland Park, Downers Grove, and Worth area.
2. Marseilles sand and gravel along the Fox River north of Elgin.

STRUCTURE

Geologic structure exercises a strong control over the irculation of ground water in the sandstone aquifers of ortheastern Illinois. Water moves eastward in the same irection as the regional dip. Modifications of the re- ional pattern of movement are brought about by: 1) umpage, 2) local structures, and 3) lithologic variations the aquifers. No evidence indicates that local folds at have axes parallel to regional dip modify the gen- ral movement of ground water down-dip.

Faults act as barriers to ground-water movement here displacements are large enough to bring imper- eable beds into contact with permeable beds, where uge or shale is smeared along the zone of displace- ent, or where a fault brecciated zone has been re- mented.

In areas of complex faulting, such as the Des Plaines ea, ground-water circulation is disturbed to the extent at recharge and flushing are difficult and the area as a hole should be avoided for ground-water development.

PUMPAGE

Pumpage use data are classified in this report accord- g to the four main categories used by the U. S. Bureau the Census. These are: 1) public, including a) mu- cipal, and b) institutional; 2) industrial; 3) rural n-irrigation; 4) irrigation, including a) farm, and golf courses and cemeteries.

Most water-supply systems furnish water for several pes of use. For example, a public supply commonly cludes water used for drinking and other domestic es, manufacturing processes, and lawn sprinkling. The ater supplies for industries as well as those for golf urses, and cemeteries, may also be used for drinking. all cases, the total pumpage may be known approxi- ately, but the final use of the water cannot always be termined.

Public water supplies furnish water that has been proved as sanitary under the supervision of health partments. Municipal systems are either publicly or ivately owned for incorporated cities or villages. Insti- tional supplies furnish sanitary water to settlements, tels, schools, and other institutions.

Any water pumped by an industry is called an indus- al supply, regardless of the use of the water.

Rural non-irrigation supplies include farm or individual residence supplies which are not under the regular supervision of a health department. These supplies may also be used for lawns and home gardens.

Irrigation water is that which is applied to the land to supplement natural soil moisture for growing plants. In the Chicago region farm irrigation is practiced primarily by commercial truck farmers. The water pumped for golf courses and cemeteries may be in part used for drinking purposes but is used chiefly for watering lawns and gardens. This use is placed in a separate category in this report because it is great enough to have marked local effects.

Pumpage is also classified according to the aquifer in which the well is finished. In the Chicago region the water is obtained from wells finished in the glacial drift, the shallow dolomite, and the Cambrian-Ordovician and Mt. Simon Aquifers. For simplicity in this report the Cambrian-Ordovician and Mt. Simon Aquifers are called deep aquifers in the tables showing pumpage. In these tables, the term "apparent source" is used because the pumped water is assigned in each well to the aquifer in which the well is finished, although many wells are open to more than one aquifer. Additional uncertainty in the classification results from the fact that in systems obtaining water from more than one source, pumpage from individual sources may not be separately recorded and their use may be irregular.

In general, glacial drift wells and dolomite wells supply residences although some municipal and industrial wells depend on these sources. The deep aquifers are used exclusively for municipal and industrial supplies.

The industrial wells generally have the most uniform pumpage over the year unless large air-conditioning installations are used or the industry is seasonal. However, if a change in operation occurs, as on strikes or vacation shut-downs, the variation in pumpage is radical and sudden.

Municipal pumpage shows a gradual change with seasons, the average winter use being about three fourths of the average summer use.

Pumpage for irrigation is fully seasonal and varies considerably from year to year, depending on weather conditions.

The reliability of pumpage data varies greatly. Municipal pumpage is nearly always metered in cities, but many smaller villages operate without meters. Only a small part of the industrial supply is metered. Pumpage data from municipalities and the larger industrial establishments are systematically recorded. The pumpage from farm wells and from the many thousands of individual residential wells is estimated on the basis of detailed surveys of a few selected sections considered typical. In some districts, the water supply from individual wells is often replaced by a municipal supply, but often the old wells are retained for certain purposes such as sprinkling. For all these reasons it is difficult to ascertain exact pumpage figures.

Public Supplies

Municipal

The data on municipal pumpage from 1938 to 1955 inclusive (table 5) have been taken as published periodically by the Illinois Department of Public Health. The data for 1957 (table 5) were collected by the State Water Survey.

In general table 5 shows a steady increase in municipal pumpage. The reductions shown for the 1938–1944 period are attributed to extension of Lake Michigan supplies to communities in Cook and Lake Counties that formerly were supplied by well water. In McHenry County the apparent decline is not real because of a change in method of estimation.

Comparison of the increase in municipal pumpage during the period 1938–1957 with the increase in population 1940–1957 (figs. 10 and 11) shows that the pumpage increased 3.7 times as fast as the population on an average yearly basis. This rapid increase in municipal pumpage is due partly to an increase in industrial use and partly to the development of new municipal supplies.

The distribution by apparent source of the total municipal pumpage of 70,403,000 gallons per day (gpd) in 1957 is shown in table 6.

Table 6 shows that the municipalities supplied from deep wells are the largest water producers. The municipalities supplied from dolomite wells, although forming the largest group, pump an intermediate amount. The ones supplied from drift wells or springs pump the least water. This generalization becomes more evident if the two largest cities having part of their supplies from drift wells, Joliet and Woodstock, are subtracted. The remaining 19 municipalities pump an average of only 120,000 gpd each.

TABLE 5. MUNICIPAL GROUND-WATER PUMPAGE
In 1,000 gallons per day

County	Year				
	1938	1944	1948	1955	1957
Cook	11,456	10,280	12,659	17,166	22,570
DuPage	4,385	6,726	7,045	9,764	15,568
Grundy	400	422	889	1,065	1,313
Kane	7,263	9,833	10,546	12,727	14,357
Kendall	110	265	265	578	596
Lake	1,080	990	1,653	1,980	2,904
McHenry	2,103	2,079	2,281	3,510	3,984
Will	4,792	4,938	5,939	8,284	9,111
Total	31,589	35,533	41,277	55,074	70,403

Institutional

Reliable data on institutional pumpage are essentially unavailable. No institution was found which metered its pumpage. At a few institutions the power for pumpage is metered separately, especially in housing groups where the water is sold to the individual houses.

Table 7 shows the total pumpage of 20 institutions in the region is estimated at 8.5 million gallons per day (mgd), the largest consumers being state institutions.

TABLE 6. MUNICIPAL PUMPAGE BY APPARENT SOURCE, 1957
In 1,000 gallons per day

County	Glacial drift aquifers	Shallow dolomite aquifers	Deep aquifers
Cook	(0)*	11,955(15)*	10,615(10)
DuPage	(0)	10,759(15)	4,809 (4)
Grundy	35 (1)	267 (2)	1,011 (4)
Kane	617 (5)	83 (2)	13,657 (8)
Kendall	450 (1)	(0)	146 (2)
Lake	551 (4)	1,349 (5)	1,004 (5)
McHenry	3,186 (6)	236 (4)	562 (1)
Will	3,621 (4)	1,136 (8)	4,354 (4)
Total	8,460(21)	25,785(51)	36,158(38)
Percent of total	12.0	36.6	51.4
Pumpage per municipality	333	552	872

* The number of municipalities is shown in parentheses.

TABLE 7. ESTIMATED INSTITUTIONAL PUMPAGE BY APPARENT SOURCE, 1957
In 1,000 gallons per day

County	Glacial drift aquifers	Shallow dolomite aquifers	Deep aquifers	Tot
Cook	negligible	2,596	71	2,6
DuPage	neg.	884	neg.	8
Grundy	neg.	neg.	neg.	ne
Kane	neg.	656	1,461	2,1
Kendall	neg.	neg.	neg.	ne
Lake	neg.	480	neg.	4
McHenry	neg.	368	neg.	3
Will	neg.	504	1,513	2,0
Total		5,488	3,045	8,5
Percent		64.4	35.6	

Industrial Supplies

Data on industrial pumpage were obtained at 1
plants, as summarized in table 8. It is likely that so
plants have been overlooked; however, they are probab
the small ones and have small pumpage. A much grea
source of error is found in inaccurate estimates
pumpage of the large industrial plants. Only a f
plants have meters to measure the pumpage, and
metered pumpage amounts to only about 10 percent
the total industrial pumpage. The remainder of
pumpage is determined from a measured or estima
time the pump operates or is estimated by factory
cials. It is assumed that the total pumpage per cou
is more nearly correct than individual plant pumpa
as compensation for errors occurs because the pump
in some plants is probably overestimated and in oth
underestimated.

The industrial pumpage is about one half that of
municipal pumpage. Nearly 94 percent of the indust
pumpage is obtained from the deep aquifers. Owing
this concentration the industrial pumpage from the d
aquifers is nearly as great as the municipal pump
from them.

TABLE 8. ESTIMATED INDUSTRIAL PUMPAGE BY APPARENT SOURCE, 1957
In 1,000 gallons per day

unty	Glacial drift aquifers	Shallow dolomite aquifers	Deep aquifers	Total
k	negligible	482	21,035	21,517
Page	neg.	784	673	1,457
ndy	neg.	neg.	neg.	neg.
ne	72	569	1,950	2,591
ndall	neg.	neg.	neg.	neg.
ke	neg.	neg.	269	269
Henry	neg.	neg.	456	456
ll	neg.	258	8,684	8,942
Total	72	2,093	33,067	35,232

Rural Non-Irrigation Supplies

Pumpage for farms and individual residences is rarely
asured. The data summarized in table 9 are estimates
ained by considering the rural population of each
nty as given in the 1950 report of the U.S. Bureau of
Census, the population increase for 1956 as shown
the Illinois Department of Public Health, and the
bable percentage of the population which depends on
ividual water supplies. Based on a survey of selected
al areas within the Chicago region, it was determined
t the per capita use averages 50 gallons per day. This
re, as determined by the sampling, should not be
fused with higher use per capita figures commonly
d which include municipal, industrial, and commer-
uses. Rural non-irrigation, in this report, refers to
estic and livestock uses.

one of this pumpage is from the deeper sandstones.
ch of the pumpage from the glacial drift is from dug
ls. Currently, many wells in the shallow aquifers are
ipped with electric pumps. Although these installa-
s are still in the minority, their pumpage is greater
use they are more convenient than manually oper-
l pumps.

he total rural non-irrigation pumpage amounts to
60,000 gpd which is about one fourth of the total
page from the shallow aquifers. The water comes
n small wells of low capacity that are distributed
erally throughout the region. Being widely dis-
uted, these wells make an efficient use of ground
er, without the problems of interference and draw-
n inherent in the industrial and municipal pumpage.

BLE 9. ESTIMATED RURAL NON-IRRIGATION PUMPAGE BY APPARENT SOURCE, 1957
In 1,000 gallons per day

ty	Glacial drift aquifers	Shallow dolomite aquifers	Total
	600	650	1,250
ge	1,300	2,200	3,500
dy	200	200	400
e	550	1,200	1,750
lall	400	210	610
	800	1,000	1,800
enry	750	300	1,050
	1,100	1,700	2,800
Total	5,700	7,460	13,160

Irrigation Supplies

Farm

There are 45 known irrigation systems in the eight counties, but only 12 of these, as summarized in table 10, use ground water. Pumpage for irrigation is irregular in that it is highly seasonal and also varies greatly from year to year. The momentary use may be high but of short duration. The total pumpage is calculated on an annual basis. Ground-water pumpage for irrigation is from the glacial drift and shallow dolomite aquifers.

Golf Courses and Cemeteries

The pumpage shown in table 11 is used primarily for irrigating grass and perennial plants in golf courses and cemeteries throughout the growing season. Wells in glacial drift aquifers were not considered in this table and are believed to be of minor significance.

TABLE 10. ESTIMATED FARM IRRIGATION PUMPAGE BY APPARENT SOURCE, 1957
In 1,000 gallons per day

County	No. of systems	Glacial drift aquifers	Shallow dolomite aquifers	Total pumpage
Cook	3	0	9.0	9.0
DuPage	1	3.5	0	3.5
Lake	1	3.0	0	3.0
McHenry	1	4.0	0	4.0
Will	6	0	12.5	12.5
Total	12	10.5	21.5	32.0

TABLE 11. ESTIMATED GOLF COURSE AND CEMETERY IRRIGATION PUMPAGE BY APPARENT SOURCE, 1957
In 1,000 gallons per day

County	Shallow aquifers	Deep aquifers	Total
Cook	188	196	384
DuPage	116	negligible	116
Kane	25	neg.	25
Lake	20	neg.	20
McHenry	8	neg.	8
Will	10	neg.	10
Total	367	196	563

Total Pumpage

The estimated total pumpage of ground water in the region for 1957 is 127.9 mgd. The distribution of pumpage by use and by apparent source is shown in tables 12 and 13 respectively. Table 12 shows that public systems took more than twice as much ground water as any other category of use and pumped 61.6 percent of the total in 1957. Table 13 shows that wells finished in the deep aquifers yielded a little more than half of the total pumpage in 1957.

Pumpage from the deep wells at six pumping centers was estimated for 1958. This estimate, with break-down into actual source, is discussed in a subsequent section.

TABLE 12. SUMMARY OF ESTIMATED TOTAL PUMPAGE BY USE, 1957

In 1,000 gallons per day

County	Public	Industrial	Rural Non-Irrig.	Irrig.	Total
Cook	25,237	21,517	1,250	393	48,397
DuPage	16,452	1,457	3,500	119	21,528
Grundy	1,313	negligible	400	neg.	1,713
Kane	16,474	2,591	1,750	25	20,840
Kendall	596	neg.	610	neg.	1,206
Lake	3,384	269	1,800	23	5,476
McHenry	4,352	456	1,050	12	5,870
Will	11,128	8,942	2,800	22	22,892
Total	78,936	35,232	13,160	594	127,922
Percent of total	61.6	27.6	10.3	.5	

TABLE 13. SUMMARY OF ESTIMATED TOTAL PUMPAGE BY APPARENT SOURCE, 1957

In 1,000 gallons per day

County	Glacial drift aquifers	Shallow dolomite aquifers	Deep aquifers	Total
Cook	600	15,880	31,917	48,39
DuPage	1,303	14,743	5,482	21,52
Grundy	235	467	1,011	1,71
Kane	1,239	2,533	17,068	20,8
Kendall	850	210	146	1,2
Lake	1,354	2,849	1,273	5,4
McHenry	3,940	912	1,018	5,8
Will	4,721	3,620	14,551	22,8
Total	14,242	41,214	72,466	127,9
Percent of total	11.1	32.0	56.7	

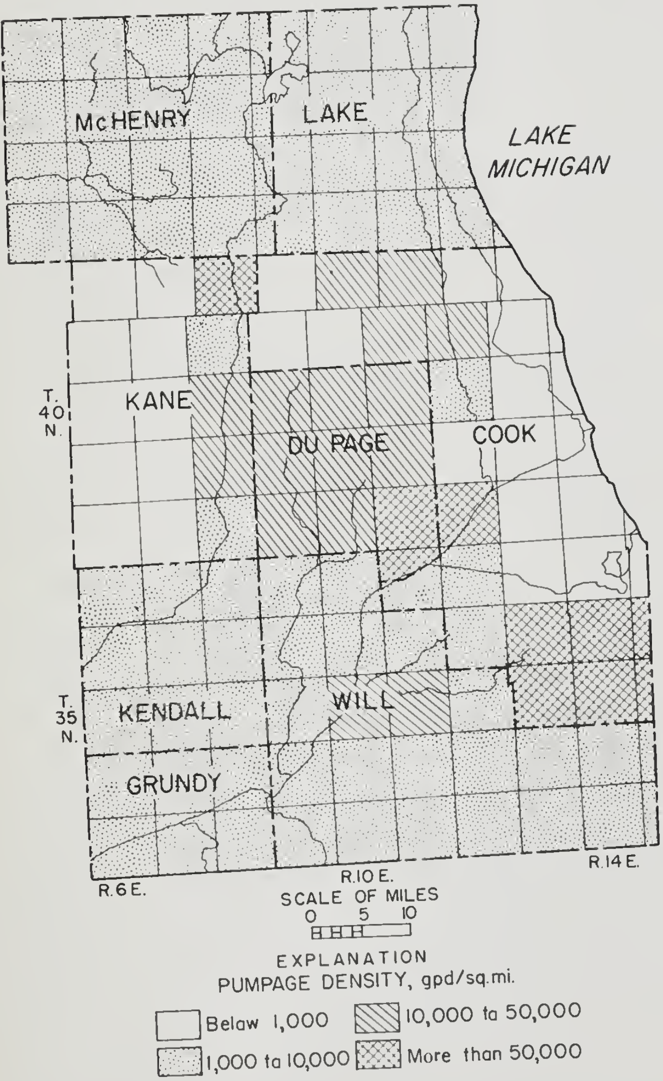


Fig. 28. Pumpage per square mile from shallow aquifers.

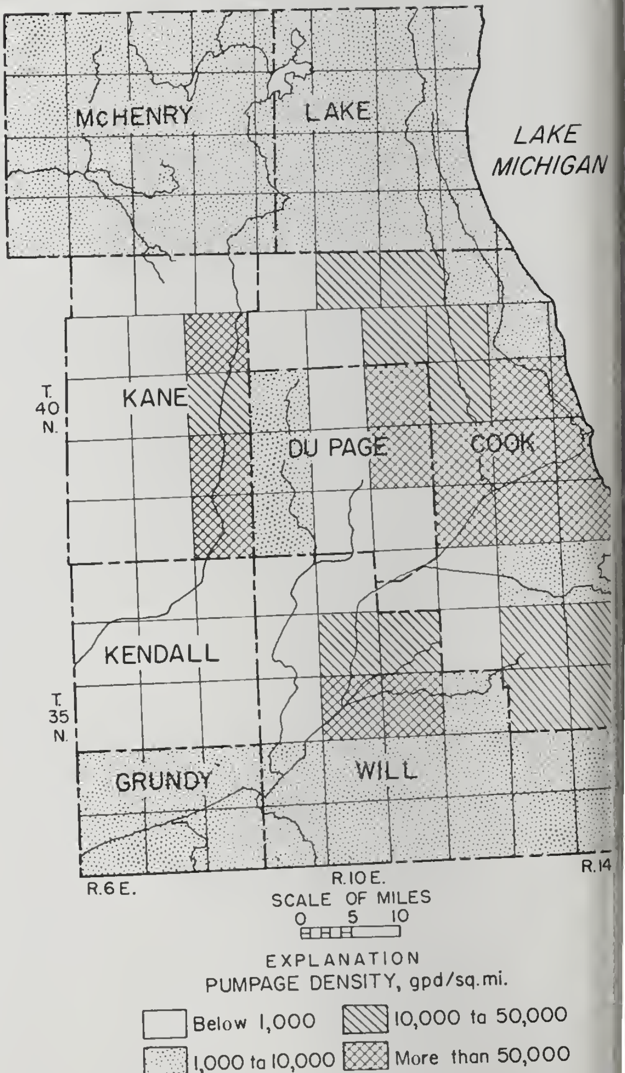


Fig. 29. Pumpage per square mile from deep aquifers.

Distribution and Density of Pumpage

Pumpage from the shallow aquifers and the deep uifers was grouped into districts consisting of one or re townships, and the average pumpage per square ile (density of pumpage) for each district was com- ited. The areal extent, pumpage, and density of pump- e for each district are given in table 14. The density pumpage for the shallow aquifers and the deep uifers in the various districts is shown graphically figures 28 and 29 respectively.

The districts having the highest densities of pumpage m the shallow aquifers are in the southeastern part DuPage County and in the western part of Cook unty. The density of pumpage is also high throughout the eastern part of DuPage County, the northwestern and southern parts of Cook County, at Joliet in Will County, and in the northern part of the Fox River Valley in Kane County. The pumpage per square mile is small in Lake, McHenry, Kendall, and Grundy Counties, indicating that pumpage from the shallow aquifers is fairly evenly distributed in these counties.

The highest density of pumpage from the deep aquifers occurs at Aurora in Kane County. High densities occur along the Fox River as far north as Elgin, in the central part of Cook County, in the northeast corner of DuPage County, and in the Joliet area. Pumpage from the deep aquifers is small in the southern part of Will County, in the northeastern part of Grundy County, and in Kendall, McHenry, and Lake Counties.

TABLE 14. GEOGRAPHIC DISTRIBUTION AND DENSITY OF PUMPAGE, 1957

Extent of district		Daily pumpage in gallons		Density of pumpage in gallons per square mile	
Township North	Range East	Shallow aquifers	Deep aquifers	Shallow aquifers	Deep aquifers
		Cook County			
35-36	13-14-15	8,140,000	4,685,000	50,246	28,919
36,37	12,11-12	275,000		3,161	
37	13-14-15	18,000	125,000	219	1,524
38	12	3,161,000	4,567,000	87,806	126,861
38-39	13-14	13,000	10,890,000	106	90,750
39	12	22,000	4,067,000	611	112,972
40	13-14	5,000	2,646,000	98	51,882
40	12	98,000	683,000	2,722	18,972
41	13-14	6,000	254,000	153	6,512
41	11-12	1,885,000	2,868,000	28,130	42,805
41,42	9-10,9	90,000		833	
42	12-13	8,000	147,000	156	2,882
42	10-11	2,759,000	985,000	38,319	13,681
		Du Page County			
37-38	11	5,568,000	20,000	109,177	392
39-40	11	2,506,000	5,204,000	34,805	72,278
38-40	10	5,119,000		47,398	
38-40	9	2,854,000	258,000	26,426	2,390
		Grundy County			
33-34	6-8	702,000	1,011,000	3,250	4,640
		Kane County			
38	8	131,000	7,879,000	3,639	218,861
39	8	975,000	2,436,000	27,083	67,666
40	8	393,000	1,528,000	10,917	42,444
41	8	231,000	5,224,000	6,416	145,122
42	8	1,853,000		51,472	
38-42	6-7	190,000		528	
		Kendall County			
35-37	6-8	1,060,000		3,272	
		Lake County			
43-46	9-12	4,852,000	1,018,000	8,146	3,784
		McHenry County			
43-46	5-9	3,723,000	1,730,000	7,941	1,666
		Will County			
33-34,35	11-15,12	1,773,000	350,300	5,756	1,137
33-34	9-10	949,000	1,211,000	6,590	8,410
35	10-11	3,013,000	9,833,000	41,708	136,572
36	10-11	661,000	3,156,000	9,331	43,840
35-37,37	9,9-10	1,345,000		9,340	

HYDROLOGY OF AQUIFERS

CAMBRIAN-ORDOVICIAN AND MT. SIMON AQUIFERS

The Cambrian-Ordovician Aquifer consists in downward order of the Galena-Platteville Dolomite, Glenwood-St. Peter Sandstone, Prairie du Chien Series, Trempealeau Dolomite, Franconia Formation, and Ironton-Galesville Sandstone. It is considered in most detail in this report.

The Ironton-Galesville Sandstone is the most productive formation of the group. The Galena-Platteville Dolomite and Prairie du Chien Series generally are not well creviced and are not major contributors. The Trempealeau Dolomite is locally well creviced and is partly responsible for exceptionally high yields of several deep wells in the Chicago-Joliet-Fox Valley area. The Mt. Simon Aquifer, consisting of the sandstone of the Mt. Simon and lower Eau Claire Formations (fig. 19), yields moderate supplies in the western part of the area where the water is of acceptable quality.

The Maquoketa Formation above the Galena-Platteville Dolomite acts as a barrier between the shallow dolomite and deeper aquifers and confines the water in the deeper aquifers under artesian pressure. Any original differences in artesian pressure among the units of the Cambrian-Ordovician Aquifer have been largely equalized by the great number of wells open in all units. Available data indicate that on a regional basis, the entire sequence of strata, from the top of the Galena-Platteville to the top of the shale beds of the Eau Claire Formation, essentially behave hydraulically as one aquifer. Some differences in pressure in the various strata probably still exist in places where the permeability of intervening beds is low and there are not enough wells to have permitted equalization. However, the entire sequence of strata is treated as one aquifer in this report.

The Mt. Simon Aquifer beneath the Eau Claire Formation is fairly permeable and yields moderate amounts of water to wells. The Cambrian-Ordovician Aquifer is effectively separated from the Mt. Simon Aquifer by impermeable beds of the Eau Claire Formation. The artesian pressure in the Mt. Simon Aquifer is greater than that in the Cambrian-Ordovician Aquifer.

In wells open to the Cambrian-Ordovician Aquifer, Silurian age dolomite, and Mt. Simon Aquifer, ground water moves downward from the dolomite and upward from the Mt. Simon into the Cambrian-Ordovician Aquifer.

Hydraulic Properties

The significant hydraulic properties of aquifers are expressed mathematically by the coefficients of transmissibility, T, and storage, S. The capacity of a formation to transmit ground water is expressed by the *coefficient of transmissibility,* which is defined as the rate of flow of water in gallons per day, through a vertical strip of the aquifer one foot wide and extending the full saturated thickness under a hydraulic gradient of 100 percent (one foot per foot) at the prevailing temperature of the water. The storage properties of an aquifer are expressed by the *coefficient of storage,* which is defined as the volume of water in cubic feet released from or taken into storage per square foot of surface area of the aquifer per foot change in the component of head normal to that surface. Under artesian conditions, water is derived from storage by the compaction of the aquifer and its associated beds and by expansion of the water itself.

Pumping Tests

The hydraulic properties of an aquifer are determined by means of pumping tests, wherein the effect of pumping a well at a known constant rate is measured in the pumped well and at observation wells penetrating the aquifer. Graphs of drawdown versus time after pumping started, and/or of drawdown versus distance from the pumped well, are used to solve equations which express the relation between the coefficient of transmissibility and storage of an aquifer and the lowering of water levels in the vicinity of a pumped well.

During the period 1922–1954, 63 pumping tests were made in northeastern Illinois to determine the hydrauli properties of the Cambrian-Ordovician Aquifer. Th data collected during the pumping tests were analyze by means of the Thiem (see Wenzel, 1942, p. 81) and the nonequilibrium (Theis, 1935, p. 519–24) formulas The Thiem formula is

$$T = \frac{527.7\ Q \log_{10} \frac{r_2}{r_1}}{s_1 - s_2} \qquad (1$$

where T is the coefficient of transmissibility, in gallon per day per foot; Q is the rate of pumping, in gallon per minute (gpm); r_1 and r_2 are the distances, in fee of two observation wells from the pumped well; and and s_2 are the respective drawdowns, in feet, in the tw observation wells.

The nonequilibrium formula is

$$s = \frac{114.6\ Q}{T} \int_u^\infty \frac{e^{-u}}{u}\, du \qquad (2$$

or, evaluating the integral,

$$s = \frac{114.6\ Q}{T} \left(-0.5772 - \log_e u + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} - \frac{u^4}{4.4!} \ldots \text{ etc.}\right)$$

where $u = \frac{1.87\ r^2S}{Tt}$; s is the drawdown, in feet, at a d tance, r, in feet, from a pumped well discharging at r Q, in gallons per minute, for a time, t, in days; T is coefficient of transmissibility, in gallons per day foot; and S is the storage coefficient of the aquifer

TABLE 15. REPRESENTATIVE COEFFICIENTS OF TRANSMISSIBILITY OF THE CAMBRIAN-ORDOVICIAN AQUIFER

County	Well owner	Depth of well (feet)	Date of test	Pumping rate (gpm)	Coefficient of transmissibility (gpd/ft)
Boone	City of Belvidere	1861	1951	615	17,500
Boone	City of Belvidere	1803	1951	540	24,200
Boone	City of Belvidere	1800	1943	852	22,500
Boone (Belvidere)	Keene Canning		1942	392	19,900
Cook	Corn Products Refining Co.	1543	1942	510	15,600
Cook	Corn Products Refining Co.	1525	1944	765	17,200
Cook	Corn Products Refining Co.	1481	1945	1020	17,200
Cook	Village of Arlington Heights	1525	1946	870	16,800
Cook	Bellwood Park Dist.	1480	1951	830	13,900
Cook	Red River Refinery	1625	1946	320	17,000
Cook	Mars Inc.	1978	1942	839	16,000
Cook	City of Chicago Heights	1794	1942	650	11,600
Cook	Village of Glenview	1251	1916	146	17,200
Cook	Baxter Lab.	1500	1946	239	15,300
Cook	Village of Mt. Prospect	1370	1951	715	18,100
Cook	Village of Riverside	2047	1944	876	17,100
Cook	Village of South Chicago Heights	2756	1941	420	10,800
Cook	Village of Willow Springs	1542	1952	1100	20,600
DeKalb	City of DeKalb	1331	1947	1000	23,200
DeKalb	City of DeKalb	1325	1930	180	18,200
DeKalb	City of DeKalb	1291	1952	1130	24,100
DeKalb	Village of Hinckley	708	1947	200	17,100
DeKalb (DeKalb)	C. M. St. P. & P. R. R.	737	1934	200	23,100
DeKalb	Village of Malta	853	1942	100	12,400
DeKalb	City of Sandwich	600	1949	730	26,900
DuPage	Village of Bensenville	1445	1954	230	17,800
DuPage	City of Elmhurst	1480	1944	625	18,000
DuPage	City of Elmhurst	1480	1944	920	14,700
DuPage	City of Elmhurst	1502	1943	950	18,300
DuPage	City of Elmhurst	1400	1948	620	18,200
DuPage	Village of Lombard	2062	1954	1200	22,000
DuPage (Villa Park)	Wander Co.	1987	1954	2390	17,600
Grundy	City of Morris	1460	1954	1470	15,900
Kane	City of Aurora	2285	1943	1120	16,400
Kane	City of Aurora	2250	1943	1476	17,700
Kane	City of Aurora	2251	1943	1300	15,700
Kane	City of Elgin	2000	1947	1124	12,600
Kane	City of Elgin	1300	1947	1146	20,100
Kane (Elgin)	Elgin National Watch	1231	1945	542	16,700
Kane	City of Geneva	1576	1946	1170	17,900
Kane	City of St. Charles	2198	1947	550	18,900
Kane	City of Batavia	1357	1953	668	20,400
Lake	Village of Lake Bluff	1804	1951	362	16,000
Lake	Onwentsia Club	1023	1949	186	15,500
LaSalle	Village of Cedar Point	1750	1922	57	13,950
LaSalle	City of Mendota	990	1949	350	15,300
LaSalle	City of Oglesby	2784	1947	350	13,500
LaSalle	City of Oglesby	2812	1949	786	19,500
LaSalle	City of Ottawa	1180	1945	1260	16,600
LaSalle (Ottawa)	Libby-Owens-Ford Glass	1168	1948	800	18,250
LaSalle (Sheridan)	Boys School 1	885	1940	170	16,100
McHenry	City of Crystal Lake	2000	1948	434	15,300
Will	Village of Elwood	1645	1941	1345	16,200
Will	Kankakee Ordnance Works	1649	1953	1253	17,400
Will	Kankakee Ordnance Works	1569	1953	1220	17,000
Will	City of Joliet	1620	1944	753	14,300
Will	City of Joliet	1544	1946	600	16,200
Will	City of Joliet	1608	1946	1290	17,100
Will	Ill. State Pen. 1	1600	1948	650	19,100
Will	Diagnostic Depot 3	1600	1948	642	19,300
Will	City of Lockport	1572	1954	700	13,000
Will	Village of Rockdale	1586	1946	293	16,500
Will	Village of Romeoville	1537	1952	1016	16,000

TABLE 16. COEFFICIENTS OF STORAGE OF THE CAMBRIAN-ORDOVICIAN AQUIFER

Location	Well owner	Date of test	Average depth of wells (feet)	Pumping rate (gpm)	Coefficient of storage
Kane County	City of Elgin	Apr., 1944	1900	750	0.00068
Joliet, Will County	Blockson Chemical Co.	Mar., 1951	1500	600	0.00037
Near Joliet, Will County	Kankakee Ordnance Works	Mar., 1943	1600	6100	0.00018
Summit, Cook County	Argo Plant, Corn Products Refining Co.	Oct., 1943	1800	700	0.00016
				Average	0.00035

A summary of the coefficients of transmissibility and storage obtained from the various pumping tests is given in tables 15 and 16. The coefficients of storage in table 16 are averages of several wells at each location.

Summary of the Results of Tests

Coefficients of transmissibility listed in table 15 range from 10,800 gpd per foot to 26,900 gpd per foot and average 17,400 gpd per foot. The coefficients of storage given in table 16 are characteristic of artesian conditions and range from 0.00016 to 0.00068 and average 0.0003 For comparison, the average coefficients of transmissibility and storage for the Cambrian-Ordovician Aquife in the Milwaukee-Waukesha area, Wisconsin (Foley Walton, Drescher, 1953, p. 72) are 23,800 gpd per foo and 0.00039 respectively.

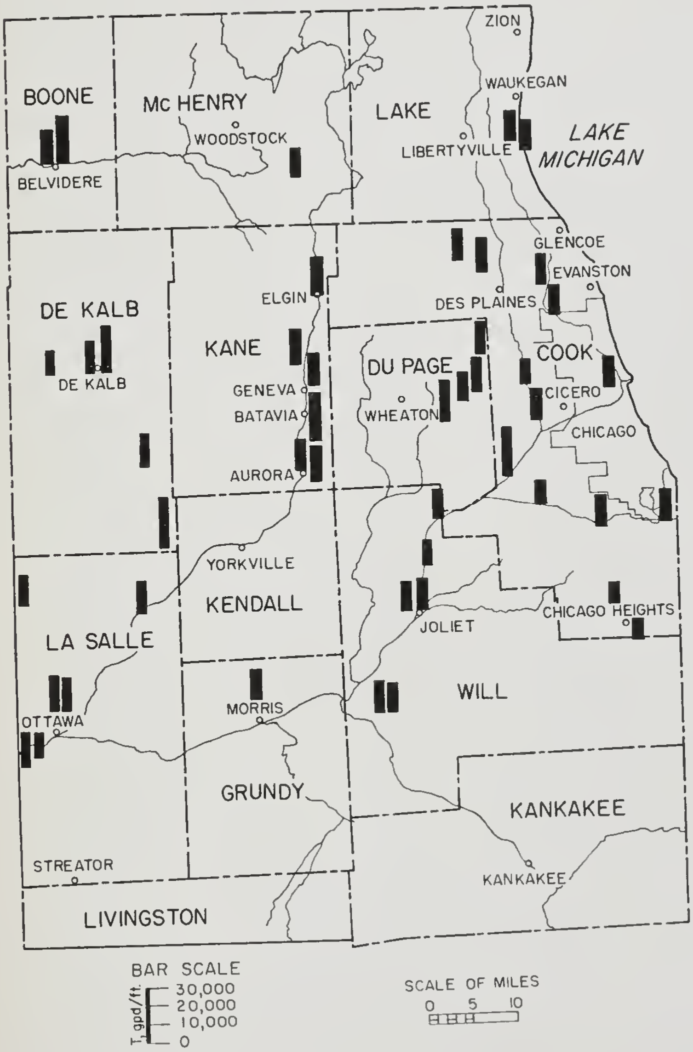


Fig. 30. Coefficients of transmissibility of Cambrian-Ordovician Aquifer.

Computed coefficients of transmissibility were used t prepare figure 30. The data indicate that the coefficier of transmissibility is fairly uniform throughout larg areas in northern Illinois. The average coefficient transmissibility of the portion of the aquifer betwee Chicago and the border of the Maquoketa Formatio (fig. 16) is 17,000 gpd per foot. Based on a study of t data in figure 30, the coefficients of transmissibility, of the aquifer decrease in a southeasterly direction fro an average value of 22,000 gpd per foot in Boone, D Kalb and LaSalle Counties to an average value of 15,0 gpd per foot in the southern parts of Cook and W Counties. Deep wells in Kankakee County and near t Indiana state line have small yields indicating that t coefficients of transmissibility of the aquifer rapid decrease south of Joliet and east of Chicago in the nort western part of Indiana.

The coefficients of storage, S, given in table 16 we computed from the results of relatively short-term tes The calculated coefficient of storage generally increa with time (Guyton, 1941, p. 770; Jacob, 1941, p. 78 Longer pumping tests would give larger coefficients storage as has been demonstrated by Jacob in an analy of data for the Kankakee Ordnance Works. Therefo for periods of pumping involving several years or mo a coefficient of storage of 0.0006, is believed to be m realistic than the determined figure 0.00035, and is u in this report.

Theoretical Effects of Pumping

The Cambrian-Ordovician Aquifer under natural c ditions, prior to development of wells, was in appr mate dynamic equilibrium in which discharge balan recharge. The small amount of water that entered aquifer in recharge areas was discharged naturally leakage through the confining bed (Maquoketa For tion) in the parts of the aquifer under artesian co tions and by leakage into the Illinois River.

The withdrawal of water by wells disturbs the nat equilibrium. Cones of depression, with centers at pumped wells, spread out in all directions and wate taken from storage within the aquifer as water levels ɔwered in the areas under the influence of pumping. 'he cones overlap and continue to grow until: (1) the ɔwering of water levels results in increased recharge to, r decreased natural discharge from, the aquifer or a ombination of these, and (2) hydraulic gradients are stablished from the recharge or natural discharge area) the pumped wells sufficient to bring from the area the mounts of water pumped. The natural discharge canot be decreased, nor the recharge increased, unless the ydraulic gradients are changed in areas of discharge nd recharge. The dimensions of the cones of depression epend largely upon the hydraulic properties of the quifer (coefficients of transmissibility and storage), the ɪcation and character of geohydrologic boundaries, and ıe rates of pumping.

Considerable time elapses before a cone of depression abilizes, water is no longer taken from storage, and a ·w state of approximate equilibrium is established. The me required to reach approximate equilibrium may be ɔmputed by using the following equation (see Foley, 'alton, Drescher, 1953, p. 86):

$$t = \frac{R^2S}{112T\epsilon \log_{10}\left(\frac{2R}{r}\right)^2}$$

ıere t = time required to reach approximate equiɔrium, in years; R = distance, in feet, from recharge ɪundary to pumped well; S = coefficient of storage; = coefficient of transmissibility, in gallons per day per ·t; r = distance, in feet, from pumped well to observaɔn point; ε = deviation from absolute equilibrium (arɪrarily assumed to be 0.05 in computations given low).

Computations made assuming distances of 47 miles ıe average distance from Chicago [Loop] to recharge ·as) from a pumped well to a source of recharge and miles from a pumped well to an observation point, licate that time in the magnitude of 180 years would pse before the cone stabilized at the observation point.

A large part of the water withdrawn from the Caman-Ordovician Aquifer during the period in which the ıe of depression is expanding and deepening is deed from storage by compaction of the aquifer and by ɔansion of the water itself.

'umping from the Cambrian-Ordovician Aquifer has videspread effect on water levels. Ground-water withıwals at Chicago affect water levels in the Joliet area l in pumping centers in Kane and DuPage Counties. e development of ground water from areas in Kane, Page, and Will Counties also affects water levels at icago. The nonequilibrium formula (2) and the co·ients of transmissibility and storage, computed from results of pumping tests, can be used to evaluate the gnitude of interference between wells and well fields l to compute the theoretical decline in artesian head any distance from a pumped well and within any gth of time after pumping is started.

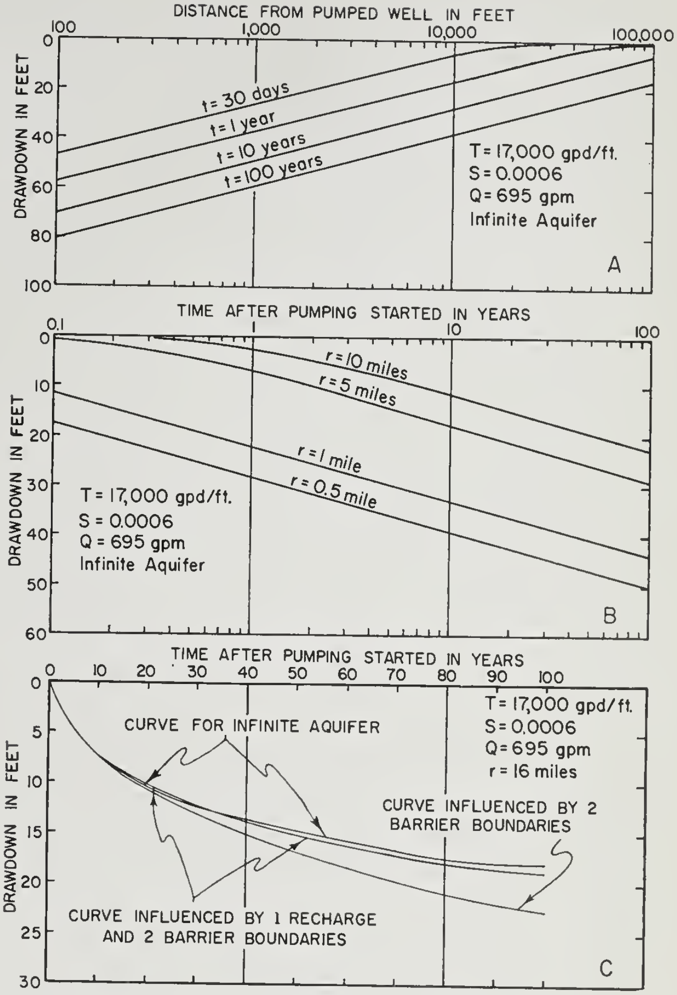


Fig. 31. Graphs of theoretical distance-drawdown (A), time-drawdown (B), and time-drawdown considering boundaries (C) for Cambrian-Ordovician Aquifer.

Figure 31A shows the amount of interference that will occur at distances of 100 feet to 19 miles from a deep well pumping continuously at 695 gpm, or 1 mgd for 30 days, 1 year, 10 years, and 100 years. The average coefficients of transmissibility and storage computed from pumping test data were used to construct the graphs. The graphs assume that all the water pumped is withdrawn from storage and that the aquifer is infinite in areal extent.

Figure 31B shows the amount of interference that will occur at any time from 37 days to 100 years 0.5 mile, 1 mile, 5 miles, and 10 miles from a well being pumped continuously at 695 gpm. Again an aquifer infinite in areal extent is assumed. The theoretical drawdown is directly proportional to the pumping rate. If the pumping rate is 347 gpm instead of 695 gpm the drawdown would be half that shown in figures 31A and 31B.

Influence of Geohydrologic Boundaries

The graphs shown in figures 31A and 31B were constructed assuming an aquifer infinite in areal extent. However, the Cambrian-Ordovician Aquifer has several boundaries. A recharge boundary exists about 47 miles west of Chicago (see subsequent section on recharge). Geologic and hydrologic data collected in northern Illinois indicate that permeabilities in the Cambrian-Ordovician Aquifer decrease south and east of Chicago and that changes in the water-bearing properties great enough to approximate the effect of barrier boundaries occur at distances of about 37 miles east and about 60 miles south of Chicago. Thus, the Cambrian-Ordovician Aquifer is enclosed by two barrier boundaries and one recharge boundary. The effect of the recharge boundary is to decrease the drawdown in a well. The effect of the barrier boundaries is to increase the drawdown in a well.

The influence of the geohydrologic boundaries, one recharge and two barrier boundaries, on the regional effects of pumping can be determined by means of the image-well theory (see Ferris, 1951, p. 247–59). The image-well theory as applied to ground-water hydrology may be stated as follows: the effect of a barrier boundary on the drawdown in a well as a result of pumping from another well is the same as though the aquifer were infinite and a like discharging well were located across the real boundary on a perpendicular thereto and at the same distance from the boundary as the real pumping well. For a recharge boundary the principle is the same except that the image well is assumed to be rechargin the aquifer instead of pumping from it.

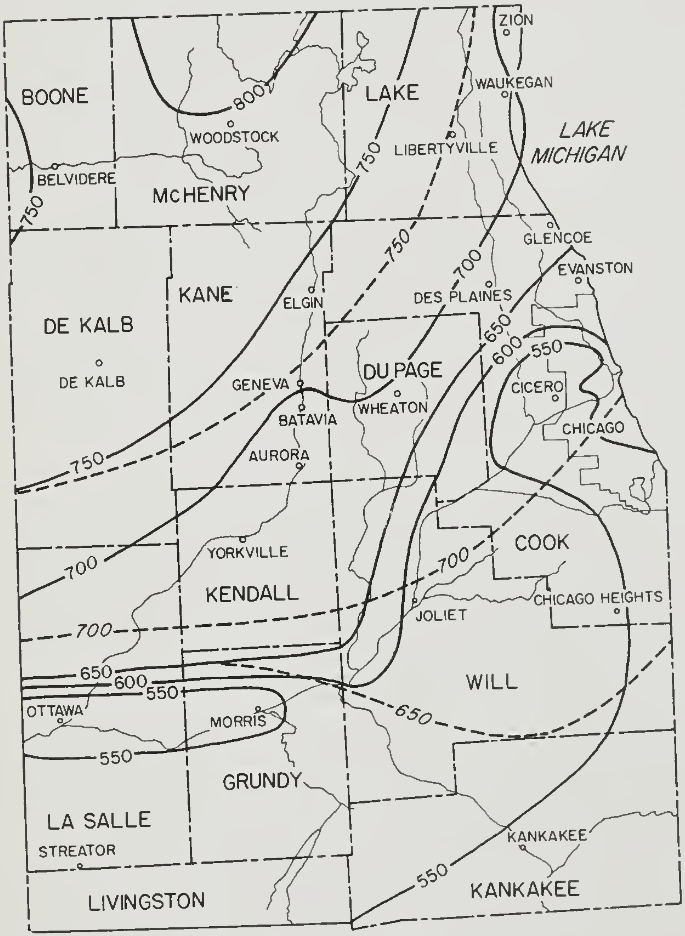


Fig. 32. Piezometric surface of Cambrian-Ordovician Aquifer about 1864 and 1895.

The recharge boundary west of Chicago and the barrier boundary east of Chicago are for practical purpose parallel. These two boundaries are intersected a approximate right angles by a barrier boundary sout of Chicago. Analysis of a multiple-boundary systen with parallel boundaries by the image-well theory requires use of a multiple image-well system (Knowle 1955, p. 88–91).

The results of geologic and hydrologic studies made i northern Illinois indicate that the effects of the ge hydrologic boundaries on the response of the Cambrian Ordovician Aquifer to development of wells can b simulated by mathematical analysis of a hypothetica hydrologic system. The system consists of a rectangula aquifer 84 miles in width enclosed by a recharge boundary 47 miles west of Chicago and by two intersectin barrier boundaries 37 and 60 miles east and south Chicago.

Figure 31C shows the effects of the geohydrolog boundaries on the drawdown at an observation point 1 miles west of Chicago. Distances from the pumped we to the observation point of 16 miles, to the rechar boundary of 40 miles, to the barrier boundary of 58 mil south of Chicago, and to the barrier boundary of miles east of Chicago were assumed in constructing t graph.

The Sandwich Fault Zone, previously discussed, ru in a northwest-southeast direction about 10 miles sout west of Joliet. There is evidence that this fault has lo effects as a barrier boundary, but it does not seem to d place or modify the regional piezometric pattern. A other geologic structure, previously described, is the D Plaines Complex which controls the hydrology local but does not seem to affect the surrounding piezomet pattern.

PIEZOMETRIC SURFACE OF CAMBRIAN-ORDOVICIAN AQUIF

The *piezometric surface* is an imaginary surface which water will rise in artesian wells. Imaginary li of equal elevation (representing equal pressure) on piezometric surface are called *isopiestic lines.* Grou water moves down gradient at right angles to isopies lines.

The exact shape of the piezometric surface of Cambrian-Ordovician Aquifer before extensive grou water development occurred in the Chicago-Joliet- Valley area is not known. However, water-level d given by Anderson (1919) and by Weidman (1915) i cate that, under natural conditions, the piezometric face was relatively featureless and sloped gently tow the southeast, as shown by the estimated isopiestic l for 1864 in figure 32. As shown in this figure, a grou

TABLE 17. WATER LEVELS IN DEEP WELLS ABOUT 1895
Elevations in Feet Above Mean Sea Level

Location	Owner	Depth of well (feet)	Surface elevation	Depth to water (ft.) above surface (+)	Date	Water-level elevation
oone County						
Belvidere	City of Belvidere	1950	755	+ 1	1891	756
ook County						
Chicago Stock Yards	Stock Yards Co.	1600-2200	592	0	1889	592
Chicago						
26th St. & Blue Island Ave.	McCormick Reaper Co.	1744	590	70	1901	520
1225 S. Campbell St.	Standard Brewery	2200	595	35	1892	560
1734 Fullerton Ave.	Deering Harvester Co.	1500	593	+ 2	1892	595
2530 Elston Ave.	Brand Brewing Co.	1600	591	60	1899	531
105th St. & Fort Wayne R.R.	Columbia Malting Co.	1250	587	63	1900	524
Clearing	Chicago & Western Indiana R.R. Co.	1600	617	93	1901	524
Forest Park	Village of Forest Park	1650	625	93	1901	532
Harvey	City of Harvey	1600	603	10	1895	593
Park Ridge	City of Park Ridge	1425	660	10	1895	650
Riverside	Village of Riverside	2000	617	20	1895	597
Kalb County						
DeKalb	City of DeKalb	890	865	65	1895	800
undy County						
Carbon Hill	Village of Carbon Hill	1900	565	+25	1893	590
Minooka	Village of Minooka	2100	614	+46	1886	660
Morris	City of Morris	765	503	+12	1894	515
ne County						
Aurora	City of Aurora	2250	630	+60	1899	690
Batavia	City of Batavia	1279	660	+20	1895	680
Elgin	City of Elgin	1350	742	11	1903	731
ke County						
Lake Bluff	Village of Lake Bluff	1900	680	+45	1885	725
Zion	City of Zion	1569	648	+35	1901	683
Salle County						
Mendota	City of Mendota	500	752	47	1895	705
Ottawa	City of Ottawa	1450	484	+22	1894	506
Peru	City of Peru	1250	475	+85	1895	560
ll County						
Joliet	City of Joliet	1550	535	+40	1895	575
Lockport	City of Lockport	1922	568	+10	1895	578
nnebago County						
Rockford	City of Rockford	1530	712	+33	1885	745

ter ridge existed in parts of McHenry, Kane, and Kalb Counties. Ground water moved under natural ditions toward Chicago from the ground-water ridge. the western part of McHenry County and in the north-st part of DeKalb County the slope of piezometric face was to the west, and the movement of water in se areas therefore was not toward the Chicago-Joliet-x Valley area but was toward the Rock River Valley. der natural conditions, the isopiestic lines bent in an stream direction around the Illinois River in Grundy l LaSalle Counties west of the border of the Maquo-a Formation, indicating that there was leakage from Cambrian-Ordovician Aquifer into parts of the Illi-s River Valley.

sian Pressure in 1864 and 1895

he first deep well in Chicago was drilled in 1864 at corner of Chicago and Western Avenues. This well 711 feet deep and probably terminated in the lower t of the Galena-Platteville Dolomite. The well flowed a head of 80 feet above the surface or to an elevation 695 feet above mean sea level. It is reasonable to ume that the water in the sandstones beneath the ena-Platteville Dolomite had a head somewhat higher that in the first drilled well. The piezometric surface of the sandstone aquifers in the Chicago area is estimated to have had an elevation of about 710 feet in 1864 as shown in figure 32. Based largely on the water-level data given by Wiedman (1915), the elevation of the piezometric surface was between 750 and 850 feet in 1864 in McHenry, Kane, Boone, and DeKalb Counties, between 40 and 140 feet higher than at Chicago. In 1864 the 650-foot isopiestic line bent southward in Will County and some water moved toward Grundy, Livingston, and Kankakee Counties south of Chicago.

Hundreds of deep wells were drilled in Chicago and in Joliet after 1864, and the pumping of large quantities of ground water changed considerably the direction and rate of ground-water movement in northern Illinois. The artesian pressure was lowered (table 17) and cones of depression were produced. As early as about 1895 the piezometric surface was greatly modified owing to heavy withdrawals of water. The hydraulic gradients from the west were steepened and the slopes of the piezometric surface east and south of Chicago were reversed, as shown in figure 32. By 1895 water was moving from nearly all directions toward Chicago and Joliet. The 700-foot isopiestic line had migrated in a northwesterly direction about 22 miles from its estimated position in

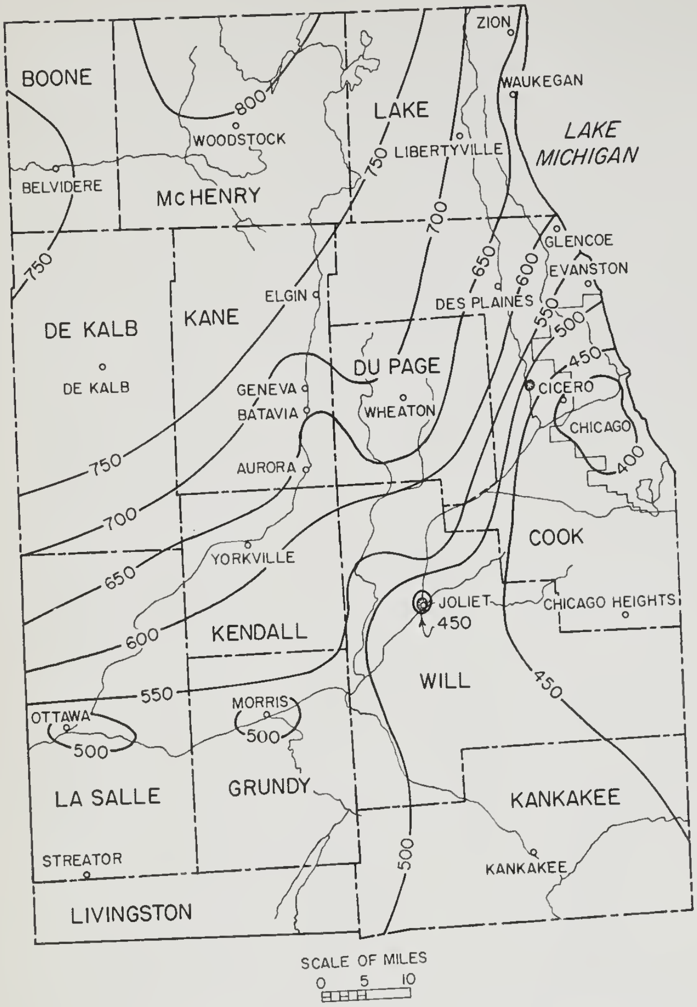


Fig. 33. Piezometric surface of Cambrian-Ordovician Aquifer about 1915.

1864. The 550-foot line had moved northwestward from northern Indiana and south of Kankakee, Illinois, to a position west of the centers of pumpage in the vicinity of Chicago, as large quantities of water were taken from storage within the aquifer.

Artesian Pressure about 1915.

Pumpage of ground water continued to increase. By 1915 the cones of depression around Chicago and Joliet had deepened since 1864 about 300 feet to elevations of about 400 feet (table 18) and isopiestic lines were distorted around pumpage centers along the Fox Valley in Kane County (fig. 33). Discharge of ground water to the Illinois River was decreased as the cone of depression moved into Kendall County. The 700-foot isopiestic line had migrated six miles from its estimated position in 1895.

Artesian Pressure in 1958

Figure 34 shows the piezometric surface of the Cambrian-Ordovician Aquifer in 1958. The levels used to prepare the map (table 19) are nonpumping water levels. Geologic cross sections and profiles of the piezometric surface of the Cambrian-Ordovician Aquifer in 1958, which were prepared for four lines across northern Illinois, are shown in figure 15. These two illustrations show clearly the cones of depression in the piezometri surface which have developed as the result of heavy pumping. It will be noted that a considerable lowerin has taken place in the pressure surface since 1915. A 400-foot isopiestic line closed around Chicago in 1915 with the cone of depression centered in the Stock Yard area. During recent years the area of lowest water level has shifted toward the west. In 1958 the deepest cone o depression in Cook County (50 feet above sea level) wa in the vicinity of Summit which is southwest of Chicag

Another pronounced cone is centered at Joliet wher the artesian pressure was at an elevation of about 2 feet above sea level in 1958. Several small cones tha developed within the large cones mentioned above di tort the isopiestic lines, causing them to bend irregularl around many scattered pumpage centers. Depressio

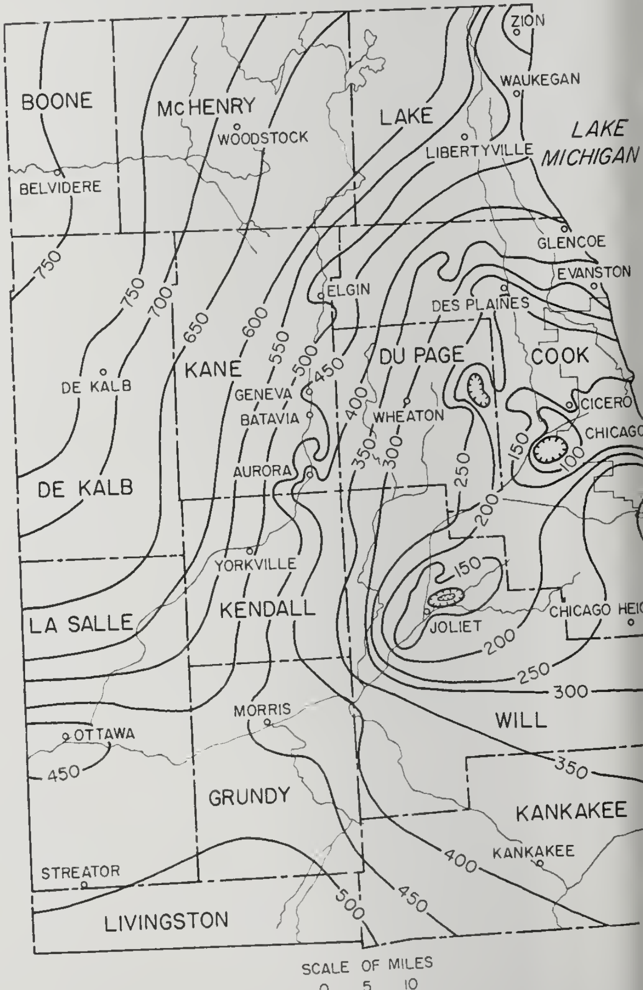


Fig. 34. Piezometric surface of Cambrian-Ordovician Aquifer in

TABLE 18. WATER LEVELS IN DEEP WELLS ABOUT 1915

Elevations in Feet Above Mean Sea Level

Location	Owner	Depth of well (feet)	Surface elevation	Depth to water (ft.) above surface (+)	Date	Water-level elevation
oone County						
Belvidere	City of Belvidere	1950	755	8	1909	747
ook County						
Summit	Corn Products Refining Co.	1638	592	187	1915	405
Bellwood	Village of Bellwood	1538	635	75	1913	560
Berwyn	City of Berwyn	1650	605	166	1914	439
Blue Island	City of Blue Island	1649	641	231	1914	410
Chicago Stock Yards	Chicago Stock Yards Companies	1600	592	239	1915	353
Chicago, Pitney Ct., & Archer Ave.	Light & Coke Co.	1800	588	213	1914	375
Chicago, 26th St. & Blue Island Ave.	McCormick Reaper Co.	1744	590	219	1914	371
Chicago, 79th St. & Blue Island Ave.	Grand Crossing Track Co.	1600	586	169	1914	417
Chicago, 1225 S. Campbell St.	Standard Brewery	2200	595	222	1914	373
Chicago, 1734 Fullerton Ave.	Deering Harvester Co.	1500	593	134	1914	459
Chicago, 2530 Elston Ave.	Brand Brewing Co.	1600	591	140	1914	451
Chicago, 105th St. & Ft. Wayne R. R.	Columbia Malting Co.	1250	587	155	1914	432
Clearing	Chicago & Western Indiana R.R. Co.	1600	617	212	1914	405
Forest Park	Village of Forest Park	1650	625	163	1914	462
Harvey	City of Harvey	1000	603	155	1915	448
Lyons	Village of Lyons	1595	615	137	1914	478
Maywood	Village of Maywood	1605	630	180	1913	450
Melrose	Village of Melrose	1620	630	80	1914	550
Park Ridge	City of Park Ridge	1425	660	85	1914	575
Summit	Village of Summit	1547	600	157	1914	443
Kalb County						
DeKalb	City of DeKalb	890	865	104	1912	761
Genoa	City of Genoa	1500	825	50	1914	775
Hinckley	Village of Hinckley	708	740	4	1913	736
Sandwich	City of Sandwich	600	667	17	1914	650
Sycamore	DeKalb-Sycamore Electric Railway Co.	1002	810	17	1914	793
Page County						
Bensenville	C. M. & St. P. & P. R.R.	2201	680	61	1913	619
Downers Grove	Village of Downers Grove	2021	717	90	1913	627
undy County						
Carbon Hill	Village of Carbon Hill	1900	565	20	1915	545
Minooka	Village of Minooka	620	620	70	1915	550
Morris	City of Morris	765	503	48	1915	455
ne County						
Aurora	City of Aurora	2185	675	48	1915	627
Aurora	Western Wheeled Scraper Co.	1410	688	78	1914	610
Batavia	City of Batavia	2000	660	6	1915	654
Elgin	City of Elgin	1350	742	14	1914	728
Geneva	City of Geneva	850	675	5	1914	670
Mooseheart	Fraternal Order of Moose	1840	709	28	1914	681
St. Charles	City of St. Charles	850	748	50	1913	698
nkakee County						
Kankakee	Kankakee State Hospital	1812	615	126	1914	489
ke County						
Lake Bluff	Village of Lake Bluff	1900	680	40	1914	640
Lake Forest	Ogden Armour Estate	1623	690	41	1915	649
Waukegan	C. & N. W. R.R. Co.	2200	600	+ 20	1914	620
ion	City of Zion	1569	648	+ 5	1914	653
Salle County						
edar Point	LaSalle County Carbon Coal Co.	1749	653	90	1912	563
LaSalle	Matthiessen & Hageler Zinc Co.	1619	585	62	1913	523
Marseilles	City of Marseilles	800	500	+ 5	1915	505
Mendota	City of Mendota	500	752	73	1915	679
glesby	City of Oglesby	1645	642	103	1915	539
ttawa	City of Ottawa	1450	484	+ 1	1915	485
eru	City of Peru	1250	475	+ 10	1915	485
treator	Various wells in City of Streator				1915	527
tica	Private wells in Utica				1915	520
County						
oliet	City of Joliet	1547	531	63	1913	468
oliet	City of Joliet	1563	544	160	1915	384
ockport	City of Lockport	1922	568	14	1915	554
lainfield	Village of Plainfield	1302	612	55	1915	557

TABLE 19. WATER LEVELS IN DEEP WELLS IN 1958

Elevations in Feet Above Mean Sea Level

Location	Owner	Depth of well (feet)	Surface elevation	Depth to water (feet)	Date	Water-level elevation
Boone County						
Belvidere	City of Belvidere	1800	778	40	1957	738
Cook County						
Chicago	American Can Co.	1806	630	492	10/57	138
Broadview	Amphenol Corp.	1550	628	475	5/58	153
Arlington Heights	City of Arlington Heights	1525	686	380	5/58	306
Arlington Heights	Arlington Park Jockey Club	1825	730	373	2/58	357
North Lake	Automatic Electric Co.	1900	655	441	5/57	214
Morton Grove	Avon Products Inc.	1525	644	335	3/58	309
Morton Grove	Baxter Lab. Inc.	1700	627	348	7/58	279
Bellwood	Village of Bellwood	1951	624	460	2/58	164
Des Plaines	Benjamin Electric Co.	1340	644	430	1/58	214
River Forest	Bowman Dairy	2072	631	458	2/58	173
Chicago	Bradshaw Praeger Co.	1204	595	474	12/57	121
Buffalo Grove	Buffalo Grove Subd.	1340	686	292	11/57	394
Chicago Heights	Calumet Steel Div.	1805	640	370	1/58	270
Elk Grove	Centex Industrial Corp.	1395	682	400	4/58	282
Berwyn	Chicago Vitreous Enamel Co.	1607	608	421	6/57	187
Bensenville	J. B. Clow & Co.	1457	663	430	8/57	233
South Chicago	Columbia Malting Co.	1400	587	430	10/57	157
Summit	Corn Products Refining Co.	1481	597	545	3/58	52
Chicago	Cracker Jack Co.	1500	620	517	4/58	103
Des Plaines	City of Des Plaines	1813	653	348	1/58	305
Elk Grove	Elk Grove Subdivision	1415	717	428	10/57	289
Glenview	Eugenia Subdivision	1414	666	341	6/58	325
Evergreen Park	Evergreen Cemetery Assoc.	1656	627	360	4/57	267
Oak Park	Fair Store	1610	619	440	6/57	179
Chicago	Fleischman Malting Co.	1900	594	530	6/57	64
Willow Springs	Ford Motor Co.	1565	617	490	11/57	127
Glenview	Glenview Club	1546	643	338	7/58	305
Mt. Prospect	Hatlen Heights Subdivision	1765	680	325	1/57	355
Roselle	Hoffman Estate Subdivision	1391	750	378	4/58	372
Elk Grove	Hotpoint Co.		698	444	7/58	254
Chicago	Ideal Roller & Mfg. Co.	1147	598	464	1/58	134
Chicago	International Harvester Co.	1600	640	452	2/57	188
Chicago	International Rolling Mill Products Co.	1617	600	488	7/58	112
Chicago	Joanna Western Mills	1603	593	465	12/57	128
Chicago	Liquid Carbonic Corp.	1512	594	456	1/58	138
Wheeling	Lonetree Subdivision	1404	686	288	5/37	398
Maywood	Village of Maywood	2018	630	482	7/58	148
Dolton	Metro Glass Co.	1704	592	432	6/58	160
Blue Island	Miller Pre-Pared Potato Co.	1651	600	392	3/58	208
Chicago	Monarch Brewery	1600	593	472	12/57	121
Mt. Prospect	Village of Mt. Prospect	1354	670	449	6/58	221
Mt. Prospect	Village of Mt. Prospect	1822	673	375	6/58	29
Blue Island	Oak Hill Cemetery	1637	667	360	5/58	30
Palatine	Village of Palatine	1350	732	362	4/58	37
Riverside	Village of Riverside	2047	618	513	5/58	10
Rolling Meadows	Village of Rolling Meadows	1530	720	374	4/58	34
Skokie	G. D. Searle & Co.	1470	614	320	7/58	29
Glenview	Signode Steel Stripping Co.	1452	670	319	6/58	35
Chicago	Standard Brands, Inc.	1545	602	466	3/58	13
Chicago	Standard Brands, Inc.	1740	602	483	11/57	11
Hinsdale	Suburban Cook Co. T. B. Sanitarium	1450	687	490	6/58	19
Thornton	Village of Thornton	1724	612	344	11/57	26
Chicago Heights	Victor Chemical Co.	1800	640	350	5/57	29
Chicago	Visking Corp.	1509	619	556	4/58	6
Western Springs	Village of Western Springs	1600	678	525	4/58	15
Wheeling	Village of Wheeling	1370	645	261	6/56	38
Chicago	Bunte Candy Co.	1951	600	458	1956	14
Glenview	Glenview Countryside Subdivision	1405	677	316	4/57	36
Glenview	Kraft Foods Research Lab.	1050	628	270	1956	3
Glenview	North Shore Country Club	2017	645	266	12/56	3
Chicago	Mars Inc.	1978	653	473	1956	1
McCook	Universal Oil Co.	1564	608	490	4/58	11
DeKalb County						
DeKalb	City of DeKalb	1331	870	168	5/58	7
DeKalb	City of DeKalb	1325	860	182	5/58	6
Sandwich	City of Sandwich	600	667	25	10/58	6
Genoa	City of Genoa	730	820	67	10/58	7

TABLE 19. (Continued)

Location	Owner	Depth of well (feet)	Surface elevation	Depth to water (feet)	Date	Water-level elevation
Page County						
Bensenville	Village of Bensenville	1442	676	448	5/58	228
Bensenville	Village of Bensenville	1445	670	431	5/58	239
Bensenville	C. M. & St. P. & P. R.R.	1461	671	443	5/58	228
Elmhurst	City of Elmhurst	2194	680	385	3/58	295
Elmhurst	City of Elmhurst	1502	690	558	4/58	132
Elmhurst	City of Elmhurst	1476	703	572	6/58	131
ombard	Village of Lombard	2028	696	467	4/58	229
ombard	Village of Lombard	1793	738	452	1/58	286
aperville	City of Naperville	1445	680	378	1/58	302
illa Park	Village of Villa Park	2125	699	494	2/58	195
illa Park	Wander Co.	1987	675	413	1/58	262
illa Park	Wander Co.	2002	670	475	11/57	195
illa Park	Wander Co.	1920	675	478	1/58	197
ndy County						
lorris	City of Morris	1501	519	108	10/57	411
lorris	City of Morris	1501	519	57	10/57	462
linooka	Village of Minooka	620	613	170	10/58	443
ne County						
urora	Alba Mfg. Co.	1543	645	272	2/58	373
urora	City of Aurora	2250	646	242	10/57	404
urora	City of Aurora	2262	619	161	10/57	458
urora	City of Aurora	2280	628	281	11/57	347
urora	City of Aurora	2299	673	259	10/57	414
urora	City of Aurora	2460	665	272	4/57	393
urora	City of Aurora	2150	660	278	8/57	382
urora	Aurora Paperboard Co.	1400	696	311	1/58	385
atavia	City of Batavia	2201	667	205	4/58	462
atavia	City of Batavia	2200	667	177	4/58	490
eneva	Burgess Norton Co.	1340	760	315	1/58	445
lgin	City of Elgin	1945	741	275	6/58	466
gin	City of Elgin	1880	745	310	6/58	435
gin	City of Elgin	1255	740	335	6/58	405
lgin	Elgin National Watch Co.	1240	734	221	1/58	513
lgin	Elgin State Hospital	2000	748	230	6/58	518
eneva	City of Geneva	2217	678	108	2/58	570
eneva	City of Geneva	1578	759	284	1/58	475
eneva	City of Geneva	2267	719	305	2/58	414
t. Charles	Ill. School for Boys	1322	790	275	12/57	515
ontgomery	Village of Montgomery	1366	633	253	11/57	380
ontgomery	Village of Montgomery	1353	640	250	1/58	390
ercyville	Mercyville	1411	697	303	12/57	394
. Charles	City of St. Charles	2200	764	285	4/58	479
uth Elgin	City of South Elgin	1400	761	250	1/58	511
urora	Walker Laundry	1438	636	320	11/57	316
est Dundee	Village of West Dundee	1200	725	216	7/57	509
rpentersville	Village of Carpentersville	1140	728	214	2/58	514
ooseheart	Mooseheart	2200	693	234	3/58	459
orth Aurora	Village of North Aurora	1272	635	214	6/57	421
lgonquin	Material Service Co.	1335	840	368	2/58	472
burn	Elburn Packing Co.	905	840	261	4/58	579
tavia	Campana	930	706	168	2/58	538
aneville	Kaneville School Dist. 302	930	740	230	8/56	510
kakee County						
ddick	Village of Reddick	1188	612	146	6/58	466
dall County						
ontgomery	Caterpillar Tractor Co.	1384	661	256	7/58	405
ontgomery	Caterpillar Tractor Co.	1352	661	236	7/58	425
ontgomery	Caterpillar Tractor Co.	1346	660	245	7/58	415
wego	Village of Oswego	1378	640	190	10/57	450
rkville	Village of Yorkville	590	584	82	10/58	502
County						
aukegan	Goodyear Tire & Rubber Co.	1631	680	154	6/52	526
aukegan	Goodyear Tire & Rubber Co.	1600	680	172	3/53	508
aukegan	Illinois Beach State Park	1002	585	150	10/57	435
ke Bluff	Village of Lake Bluff	1825	685	211	11/56	474
ges Lake	Wildwood Subdivision	1310	810	216	1951	594
on	City of Zion	1025	630	210	10/57	420
ncolnshire	Lincolnshire Subdivision	1305	645	230	12/57	415
lle County						
tawa	City of Ottawa	1180	488	40	6/58	448
rlville	City of Earlville	625	700	28	10/58	672

TABLE 19. (Continued)

Location	Owner	Depth of well (feet)	Surface elevation	Depth to water (feet)	Date	Water-level elevation
Livingston County						
Cardiff	Cardiff	1785	638	121	10/58	517
Odell	Village of Odell	1941	720	129	10/56	591
McHenry County						
Crystal Lake	City of Crystal Lake	1218	917	293	3/57	624
Crystal Lake	City of Crystal Lake	1555	930	295	3/57	635
Huntley	Dean Milk Co.	1610	890	159	7/58	731
Island Lake	Village of Island Lake	1223	775	136	7/57	639
Marengo	City of Marengo	1028	817	116	4/58	701
Ogle County						
Rochelle	City of Rochelle	550	820	40	10/58	780
Will County						
Joliet	American Cyanimid Co.	1614	586	405	6/58	181
Joliet	Amercian Institute of Laundering	1608	569	383	6/58	186
Joliet	American Oil Co.	1422	568	307	10/57	261
Joliet	Blockson Chemical Co.	1520	548	523	1/58	25
Joliet	Blockson Chemical Co.	1506	583	503	2/58	80
Joliet	Blockson Chemical Co.	1536	567	505	7/57	62
Joliet	Bohemian Brewing Co.	1484	544	391	3/58	153
Joliet	Caterpillar Tractor Co.	1510	544	360	6/57	184
Joliet	Caterpillar Tractor Co.	1543	546	360	6/57	186
Joliet	DuPage River Farm	1520	587	301	12/57	286
Joliet	Illinois State Penitentiary	1550	549	444	5/58	105
Joliet	Illinois State Penitentiary	1518	560	488	5/58	72
Stateville	Illinois State Penitentiary	1600	645	480	4/58	165
Joliet	City of Joliet	1575	535	379	3/58	156
Joliet	City of Joliet	1621	536	405	4/58	131
Joliet	City of Joliet	1535	529	401	6/58	128
Joliet	City of Joliet	1608	564	415	5/58	149
Joliet	City of Joliet	1608	558	493	6/58	65
Joliet	Hadley Valley	1660	648	450	3/57	198
Joliet	Hadley Valley	1701	674	540	10/57	134
Elwood	Joliet Arsenal (Elwood)	1645	641	284	5/58	357
Kankakee	Joliet Arsenal (Kankakee)	935	572	203	5/58	369
Joliet	Joliet Industries Inc.	1596	551	427	1/58	124
Joliet	Joliet Township High School	881	535	423	6/58	112
Joliet	Joyce 7-Up Co.	724	628	86	5/58	542
Lidice	Lidice Subdivision	1652	659	496	5/58	163
Lockport	City of Lockport	1446	589	466	1/58	123
Lockport	City of Lockport	1571	662	485	1/58	177
Lockport	City of Lockport	1572	650	508	1/58	14
Joliet	Phoenix Mfg. Co.	1595	553	441	6/58	11
Joliet	Prairie State Paper Co.	700	576	184	5/58	39
Joliet	Pratt Mfg. Co.	1505	551	458	6/58	9
Joliet	Public Service Co. of Northern Illinois	1608	518	376	7/57	14
Joliet	Public Service Co. of Northern Illinois	1507	590	375	3/57	21
Plainfield	Village of Plainfield	1481	622	316	5/58	30
Rockdale	Village of Rockdale	1586	556	424	6/58	13
Joliet	Ruberoid Co.	776	551	512	6/58	3
Joliet	Stepan Chemical Co.	1407	525	262	5/58	26
Lockport	U. S. War Dept., Lockport Locks	815	581	443	5/58	13
Joliet	Will County Sanatorium	864	622	435	6/58	18
Winnebago County						
Rockford	City of Rockford	1102	730	50	5/58	68

in the piezometric surface occur in the vicinity of Elmhurst and at Des Plaines. A significant feature shown in figure 34 is the bending of isopiestic lines around pumpage centers in the Elgin and Aurora areas along the Fox Valley in Kane County.

Changes in artesian pressure produced by pumping since the days of early settlement have been pronounced and widespread. The artesian pressure in the vicinity of Chicago has declined on the average about 600 feet. In 1864 the 700-foot isopiestic line passed through Chicago. By 1958 the 700-foot isopiestic line had migrated northwestward about 52 miles to a position in western McHenry County and eastern DeKalb County. A ground-water divide exists in eastern Boone County a
in northeastern DeKalb County.

The general pattern of flow of water in the Cambri
Ordovician Aquifer in 1958 is slow movement from
directions toward the deep cones of depression cente
at Chicago and at Joliet. Some of the water flow
toward Chicago and Joliet is intercepted by cones
depression developed locally within the large cones
the Aurora, Elgin, Des Plaines, and Elmhurst ar
The lowering of head that has accompanied the w
drawals of ground water has established steep hydra
gradients west and north of Chicago, and large qua
ties of water are at present being transmitted f

harge areas in northern Illinois and minor quantities m southern Wisconsin toward centers of pumping. rge amounts of water derived from storage within Cambrian-Ordovician Aquifer move toward Chicago d Joliet from the east in Indiana, from the south in nkakee County in Illinois, from the west in northern inois, and from the northeast beneath Lake Michigan. obably there is now some recharge into the aquifer m the Illinois River Valley in areas of extensive clines in water levels in Grundy and LaSalle unties.

Recharge to Cambrian-Ordovician Aquifer

Maps and profiles of the piezometric surface of the mbrian-Ordovician Aquifer in figures 32, 33, 34 and show high elevations in McHenry, Boone, and DeKalb unties indicating recharge in these areas. The high vations in McHenry and Boone Counties extend into sconsin. The piezometric surface reaches crests stly in areas where the Galena-Platteville Dolomite ps out at the surface or is the uppermost bedrock mation below the glacial deposits, west of the border he Maquoketa Formation shown in figure 16. In most ts of the Chicago-Joliet-Fox Valley area the Maquoketa Formation is relatively impervious and greatly retards the vertical movement of water to the underlying aquifers. However, in parts of McHenry, Kane, and DeKalb Counties, the Maquoketa Formation contains appreciable dolomite, is relatively thin, and locally may be completely removed by erosion. Recharge occurs through the formation in these areas. As a result areas of high elevation on the piezometric surface occur at some places east of the border of the Maquoketa Formation.

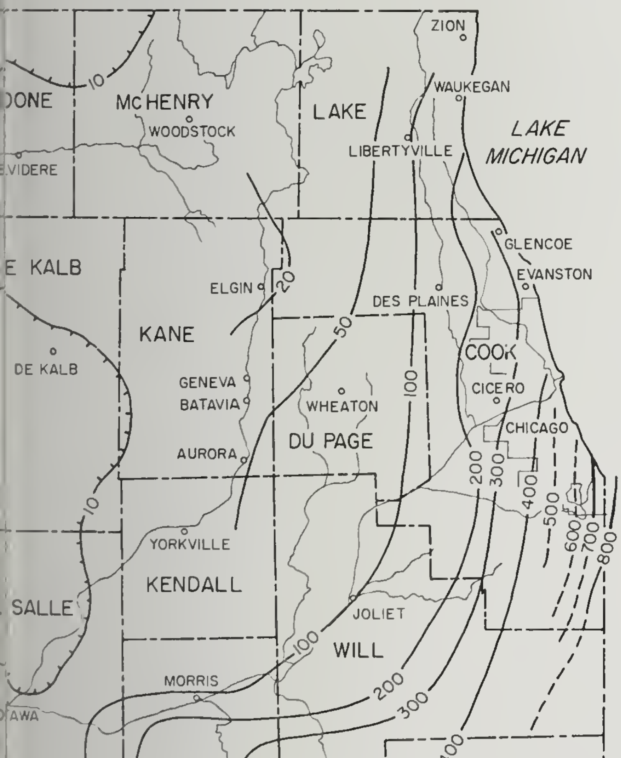


Fig. 35. Sulfate content of waters from the Cambrian-Ordovician Aquifer.

Where the Galena-Platteville Dolomite is overlain by the Maquoketa Formation there has been only small development of crevices and, although the dolomites yield some water, they are in general not very permeable. Where the Galena-Platteville Dolomite is overlain by glacial deposits more crevices are developed and the rock is fairly permeable. Thus, there is a good hydraulic connection between the Glenwood-St. Peter Sandstone and glacial deposits in areas where the Maquoketa Formation is absent or where the Maquoketa Formation overlying the Galena-Platteville is thin and dolomitic.

The Ironton-Galesville Sandstone receives water from the Glenwood-St. Peter Sandstone through crevices and other openings in the intervening dolomites. Thus, recharge to the Glenwood-St. Peter Sandstone, and eventually to the Ironton-Galesville Sandstone below, takes place generally through fractures and solution channels in the Galena-Platteville Dolomite which in turn receives water from the overlying glacial deposits. Recharge of the glacial deposits occurs from precipitation that falls locally. The indicated total area of recharge to the Cambrian-Ordovician Aquifer is about 1200 square miles.

In northern Illinois, waters from glacial sand and gravel deposits immediately overlying bedrock contain less than 10 parts per million (ppm) sulfates whereas the sulfate content of water from the Cambrian-Ordovician Aquifer is usually higher. Where waters from the Cambrian-Ordovician Aquifer contain less than 10 ppm sulfates, it is concluded that these waters have been recharged through the overlying strata (Foley and Smith, 1954, p. 229). The distribution of sulfates in water from the Cambrian-Ordovician Aquifer shown in figure 35 indicates approximately the same areas of recharge as do the piezometric-surface maps. Further confirmation of the location of the recharge area is given by the temperature of the water as explained in the subsequent section on water quality.

It is probable that a small amount of recharge occurs directly through the Maquoketa Formation under the influence of an extensive cone of depression in the Cambrian-Ordovician Aquifer.

The location of the Chicago region adjacent to the Lake Michigan basin prompts a consideration of Lake Michigan as a potential source of recharge for the deep aquifers. As shown by the succession of piezometric maps it is clear that the original conditions precluded any recharge from the lake basin. However, with the decline of the piezometric surface due to pumpage in future years to a level well below lake level and the indicated possibilities of some movement of water through the Maquoketa Formation barrier, minor amounts of recharge may be derived in the future from the Lake Michigan basin. The present study indicates no significant amount of recharge from Lake Michigan at this time.

Movement of Water in Cambrian-Ordovician Aquifer

The quantity of water percolating through a given cross section of an aquifer is proportional to the hydraulic gradient (slope of the piezometric surface) and the coefficient of transmissibility, and it can be computed by using the following modified form of the Darcy equation (see Ferris, 1951, p. 226):

$$Q = TIL \qquad (3)$$

in which Q is the discharge in gallons per day; T is the coefficient of transmissibility in gallons per day per foot; I is the hydraulic gradient in feet per mile; and L is the width of the cross section through which discharge occurs in miles.

A study was made of the movement of ground water towards Chicago in response to the natural hydraulic gradient of the piezometric surface. Flow lines were drawn from McHenry and Kane Counties toward the northern and southern boundaries of Cook County at right angles to the estimated piezometric surface contours for 1864 given in figure 32. These two flow lines delimit the section of the Cambrian-Ordovician Aquifer through which water was transmitted to Chicago under natural conditions. Considering the section of the aquifer midway between the 750-foot and 700-foot contours, the hydraulic gradient was 1.7 feet per mile and the distance between the limiting flow lines was 30 miles. Based on the data summarized in figure 30, the average coefficient of transmissibility of the section of the aquifer between the 750-foot and 700-foot lines is about 17,000 gpd per foot. Using equation (3) and the data given above, the quantity of water moving towards Chicago is computed to be about 900,000 gpd which was all that moved in this direction under the natural hydraulic gradient of the piezometric surface before pumping started.

In 1958 the amount of water moving through the Cambrian-Ordovician Aquifer southeastward from McHenry and Kane Counties was determined to be about 19 mgd, or about 20 times that flowing under natural conditions. This results from about a tenfold increase in hydraulic gradient (fig. 34) and an increase in the distance between limiting flow lines.

The cone of depression at Joliet was studied to check the accuracy of the coefficients of transmissibility computed from the results of pumping tests. The area bounded by isopiestic lines having elevations of 200 and 150 feet (fig. 34) was selected for the analysis.

From equation (3)

$$T = \frac{Q}{IL} \qquad (4)$$

The quantity of water, Q, moving midway between th 200-foot and 150-foot isopiestic lines is equal to the tota pumpage (11.6 mgd, fig. 36B) from the Cambrian Ordovician Aquifer in the Joliet area minus the amoun of water taken from storage within the area enclosed b the 150-foot isopiestic line. The amount of water take from storage is very small; therefore, Q is essentiall equal to 11.6 mgd. The hydraulic gradient, I, and th length of cross section, L, midway between the 200-foo and 150-foot isopiestic lines, were scaled from figure 3 Computations made using the data mentioned above an equation (4) indicate that the average coefficient o transmissibility of the part of the Cambrian-Ordovicia Aquifer within the Joliet cone of depression is 16,60 gpd per foot. This value compares favorably with th coefficients of transmissibility computed from the resul of pumping tests in the Joliet area (table 15).

Quantity of Water from Recharge Areas in 1958

The piezometric-surface map given in figure 34 ind cates that in 1958 some water was transmitted fro recharge areas in Walworth County in southeaste Wisconsin to cones of depression in northeastern Illinoi Because of the lack of piezometric data for the aquif where it extends under Lake Michigan, it is impossib to compute with any degree of accuracy the quantity water involved. A reasonable estimate, based on t hydraulic gradient midway between the 700-foot a 650-foot lines in McHenry County, is about 2 mgd.

Based on a study of the movement of water throu sections of the Cambrian-Ordovician Aquifer near t border of the Maquoketa Formation, it is estimated th in 1958 approximately 20 mgd were transmitted fr recharge areas in northeastern Illinois and southeaste Wisconsin toward cones of depression along the F Valley, in the vicinity of Chicago, and at Joliet.

Limiting flow lines were drawn from recharge ar through DeKalb, Kendall, LaSalle, and Grundy Co ties to the Joliet cone of depression. The quantity water transmitted in 1958 from recharge areas towa Joliet was computed to be 5.8 mgd. The calculation based on the movement of water through the section the aquifer midway between the 500-foot and 450-f lines near the border of the Maquoketa Formation a enclosed by the limiting flow lines. The total quant of water pumped from the Cambrian-Ordovician Aqui is derived from recharge areas and from storage wit the aquifer. Thus, of the total 11.6 mgd of wa pumped from the Cambrian-Ordovician Aquifer in 1 in the Joliet area, 5.8 mgd of water, or 50 percent, derived from storage within the aquifer.

Quantity of Water Moving into Cones of Depression in 1958

The quantities of water percolating in 1958 thro sections of the Cambrian-Ordovician Aquifer into cones of depression in the Aurora, Elgin, Des Plai Elmhurst, Joliet, and Chicago areas were computed using data in figures 30 and 34 and equation (3), t as given in table 20.

ABLE 20. AMOUNT OF WATER MOVING INTO THE CONES OF DEPRESSION OF PUMPING CENTERS IN 1958

Pumping center	Water (*mgd*)
Chicago area	11.0
Joliet area	11.6
Elmhurst area	5.3
Des Plaines area	3.5
Elgin area	4.1
Aurora area	7.3
Total	42.8

Many deep wells in the Chicago-Joliet-Fox Valley area e uncased in the Mt. Simon Aquifer as well as in the ambrian-Ordovician Aquifer and the Silurian age dolo- ite. Thus, a large portion of the water pumped from ep wells is obtained from the aquifers above and low the Cambrian-Ordovician Aquifer. The differ- ice, 33.3 mgd, between the total pumpage of 76.1 mgd om deep wells in the Chicago-Joliet-Fox Valley area d the total of 42.8 mgd of water diverted into the cones depression is the amount of water derived from the t. Simon Aquifer and the Silurian age dolomite.

Discharge from Deep Wells

mpage

The first deep well in Chicago, drilled at the corner of icago and Western Avenues in 1864, had an artesian w estimated at about 150 gpm or about 200,000 gpd. e estimated pumpage from deep wells in the Chicago- liet-Fox Valley area increased gradually from 200,000 d in 1864 to more than 76 mgd in 1958. Figure 36 ows estimated withdrawal rates for 1864–1958 in the major pumping centers of the Chicago-Joliet-Fox lley area. Records of pumpage are fairly complete for period 1942–1958; very few records of pumpage are ailable for years prior to 1942. The graphs in figure 36 re constructed by piecing together fragments of infor- tion on pumpage found in published reports and in files of the State Water Survey, by making evalua- ns based on the number of wells, their reported lds, and their time of construction, and by taking o consideration population growth and per capita nsumption.

TABLE 21. DISTRIBUTION OF PUMPAGE FROM DEEP WELLS IN 1908 AND 1958

Pumping center	1908 Total pumpage (*mgd*)	1958 Total pumpage (*mgd*)
cago area	21.3	23.4
et area	1.8	14.0
lhurst area	0.4	9.8
Plaines area	0.4	6.8
in area	2.6	8.1
ora area	3.9	14.0
Total	30.4	76.1

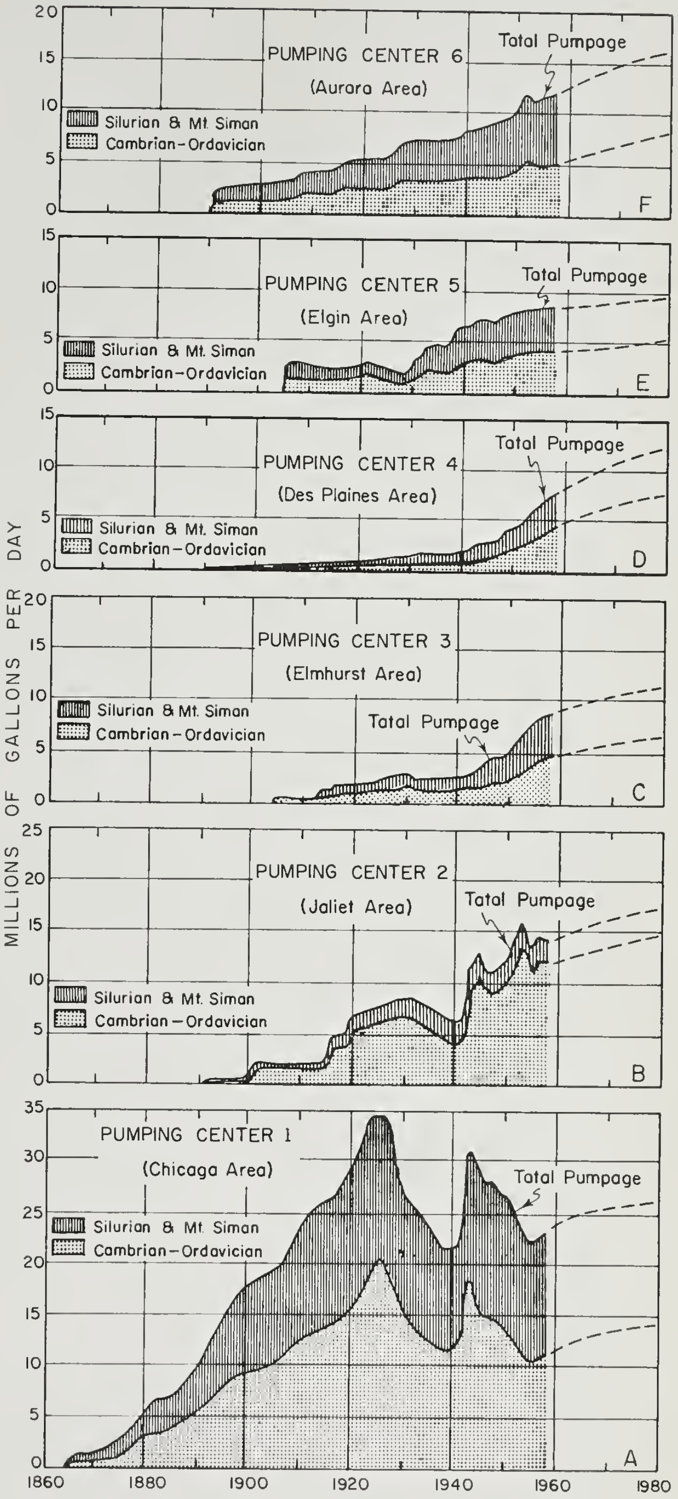


Fig. 36. Pumpage from the deep wells for the period of record.

Figure 37 and table 21 show the distribution of estimated pumpage from deep wells in 1958. The greatest quantities of water were withdrawn from deep wells in the Chicago, Joliet, and Aurora areas.

In 1908, 50 years ago, there was very little pumpage outside Chicago except at Aurora and Elgin (table 21). Since that time the net increase in pumpage at Chicago has been only about 10 percent although in the 1920's and 1940's much higher pumping rates were obtained. Pumpage in areas near Chicago (Elmhurst and Des Plaines) has increased to 15 times that recorded in 1908. During the past 50 years, pumpage at Joliet has increased from 1.8 to 14.0 mgd and pumpage along the Fox Valley in the Aurora and Elgin areas has more than tripled.

As shown in figures 36C and D, prior to about 1940 pumpage in the Elmhurst and Des Plaines areas increased fairly uniformly at an average rate of about 50,000 gpd per year. The total pumpage in 1940 was 2.3 mgd in the Elmhurst area and 1.7 mgd in the Des Plaines area. During and after World War II, pumpage in these two areas increased very rapidly at an average rate of 400,000 gpd per year, or at a rate 8 times that recorded for the period prior to 1940.

The rate of increase in withdrawal in the Aurora area has been very uniform since 1890 and has averaged about 110,000 gpd per year. Pumpage in the Elgin area increased gradually during the period 1904–1928 after which it increased rapidly until about 1952. From 1952 to 1958 pumpage at this center has remained fairly constant at about 8 mgd.

As shown in figure 36B, pumpage in the Joliet area greatly increased during World Wars I and II and the Korean War in response to water demands of manufacturing industries. Pumpage at Joliet has also fluctuated with economic conditions as indicated by the decrease in pumpage during the 1930's.

Pumpage in the Chicago area increased at a rapid rate from about 200,000 gpd in 1864 to a maximum of 34.4 mgd in 1924. During the period, 1925–1937, pumpage decreased rapidly as many industries, including the Stock Yards, abandoned deep wells owing to the great decline in artesian pressure and began using the city of Chicago water supply. Economic conditions during the depression in the 1930's also contributed to the decrease in pumpage at Chicago. From 1940 to 1942 pumpage increased rapidly from 21.6 to 31 mgd, and after that it decreased to 22 mgd in 1954 and was 23.4 mgd in 1958.

Quantity of Water Derived from Silurian Age Dolomite and Mt. Simon Aquifer

The amount of water derived in 1958 from the Silurian age dolomite and the Mt. Simon Aquifer was calculated using figures 30 and 34 and equation (3) by subtracting the amounts of water moving through the Cambrian-Ordovician Aquifer into the pumping centers from the total withdrawals from deep wells in the pumping centers. Figure 37 shows the distribution of estimated pumpage from the Silurian age dolomite and Mt. Simon and Cambrian-Ordovician Aquifers in 1958. In 1958 about 33.3 mgd or 43 percent of the total amount of 76 mgd pumped from deep wells was derived from the Silurian age dolomite and the Mt. Simon Aquifer. Based on an inventory of well construction and quality of wa
studies, it is estimated that in 1958 about 20.5 mgd w
derived from the Silurian age dolomite and about 1
mgd were obtained from the Mt. Simon Aquifer. A la
part of the water derived from the Mt. Simon Aqu
was pumped from deep wells in the Fox Valley.

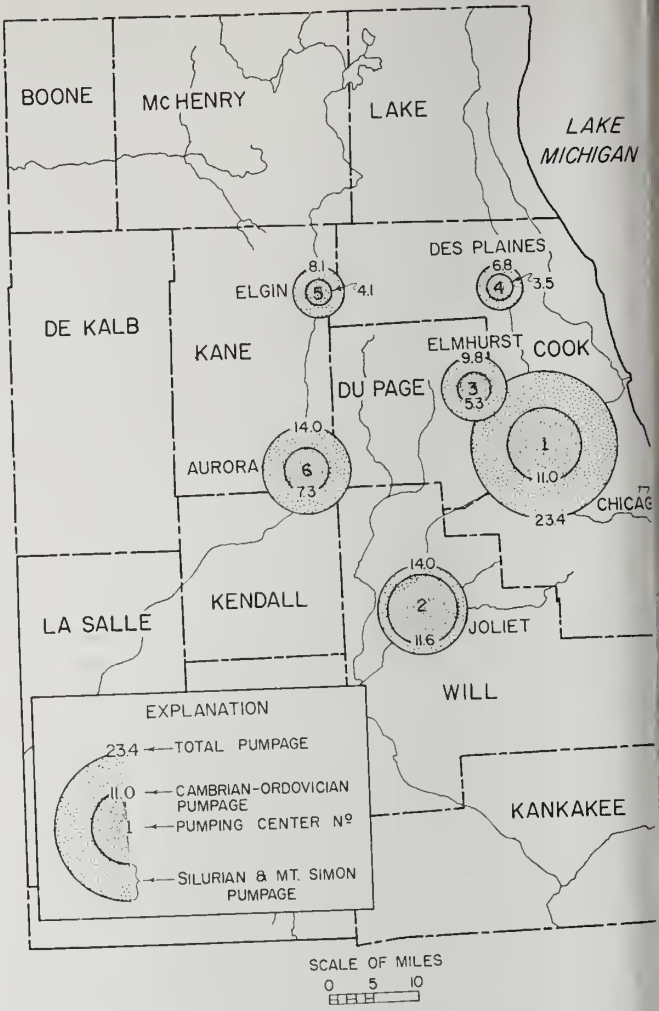


Fig. 37. Distribution of estimated pumpage from deep wells in I
Pumpage is proportional to radius of circle.

Figure 36 gives approximate amounts of water deri
from Silurian age dolomite and the Mt. Simon and C
brian-Ordovician Aquifers in the pumping centers p
to 1958. The figure was constructed after conside
mineral content and temperature data and by evalua
the number of wells open in the Cambrian-Ordovi
Aquifer, the Silurian age dolomite, and/or the Mt. Si
Aquifer, their yield, and their time of construction
is estimated that the amount of water derived f
sources other than the Cambrian-Ordovician Aq
increased from about 16.4 mgd in 1915 to 33.3 mg
1958. Also considered was the fact that leakage of w
from the Silurian age dolomite into deep wells rem
fairly constant after the artesian pressure in the C
brian-Ordovician Aquifer declines below the base o
Silurian age dolomite.

DECLINE OF ARTESIAN PRESSURE IN CAMBRIAN-ORDOVICIAN AQUIFER

In 1864 the artesian pressure in the Cambrian-Ordocian Aquifer was sufficient to cause wells to flow in any parts of the Chicago-Joliet-Fox Valley area. The timated isopiestic lines in figure 32 indicate that in 64 the average elevation of the piezometric surface at hicago and Joliet was about 700 feet. By 1895 the presre had dropped in response to withdrawals of water elevations of about 550 feet at Chicago and 600 feet Joliet. In a period of 31 years, water levels at Chicago d declined about 150 feet or at a rate of about five feet r year because large amounts of water were being ken from storage within the aquifer. As pumping conued, the nonpumping water levels continued to cline, and by 1915 were 400 feet above sea level at icago and Joliet. The average rate of decline and al decline in artesian pressure at Chicago, 1895–1915, re about 7.5 feet per year and 150 feet respectively.

As a result of continued heavy pumping, the nonmping water levels in deep wells declined from an vation of 400 feet in 1915 to about 50 feet at Chicago d about 25 feet at Joliet in 1958 (fig. 34). The average e of decline at Chicago in the 43-year period, 1915–8, was eight feet per year. In many areas the average e of decline has increased during recent years to more n 10 feet per year in response to progressive increases pumpage.

Since 1864 the artesian pressure at Chicago has deed about 660 feet. The average rate of decline, 1864–8, was 7.1 feet per year. Figures 38 and 39 show the es of decline of artesian pressure at Chicago and at iet.

The estimated piezometric surface map for 1864 (fig. was compared with the piezometric surface map for 8 (fig. 34). Figure 40 shows the decline of water ls in the Cambrian-Ordovician Aquifer, 1864–1958. lines representing decline closely conform in most as to the 1958 isopiestic lines. The greatest declines, ounting to more than 600 feet, have occurred in areas eavy pumpage just west of Chicago, at Summit, and Joliet. The decline has been 10 feet or less west of the rgin of the Maquoketa Formation in recharge areas DeKalb, Boone, and McHenry Counties. Most of the line in the recharge areas is due to local pumpage and not be attributed to heavy pumping at Chicago and et.

here has been fairly widespread decline of more than feet west of the margin of the Maquoketa Formation outhwestern Kendall County, northwestern Grundy nty, and LaSalle County. The hydraulic gradients hese areas have been readjusted to divert large quans of water from the recharge areas into the Joliet Chicago cones of depression.

he lines representing decline are distorted around Illinois River in Grundy County, lending support he conclusion that there is some hydrologic conion between the Cambrian-Ordovician Aquifer and the Illinois River west of the border of the Maquoketa Formation.

Quantity of Water Taken from Storage Within Cambrian-Ordovician Aquifer

The volumetric change of ground-water storage cannot be determined precisely owing to the lack of water-level data for the area underlying Lake Michigan and the areas southeast of Chicago and south of Kankakee. However, conditions in areas not covered by the map in figure 40 can be estimated with reasonable accuracy by extrapolating existing data. Based largely on the data given in figure 40 and using a coefficient of storage of 0.0006, it is estimated that about 340 billion gallons of water were taken from storage within the aquifer during the period 1864–1958. The average rate of volumetric decrease of ground-water storage, 1864–1958, was about 10 mgd.

The average rate of decline of water levels in the Chicago-Joliet-Fox Valley area from 1864 to 1958 was 5.2 feet per year or a little less than one half the annual rate of 11 feet for the period 1949–58. Computations show that the average rate of volumetric decrease in ground-water storage, 1949–58, was about 23 mgd. Thus, in 1958 about 23 mgd were taken from storage within the aquifer to balance pumpage.

APPLICATION OF HYDROLOGIC SYSTEM TO PAST RECORDS

Records of past pumpage and water levels were used to determine whether or not the hypothetical hydrologic system discussed earlier in this report satisfies the geohydrologic limits of the aquifer. The reason for doing this is to test the assumed model against past performance and thereby establish the validity of this mechanism to predict future water levels in the region.

The water-level decline in the Lisle area in DuPage County from 1864 through 1958 was computed as a test (fig. 40), using calculated coefficients of transmissibility and storage and estimated pumpage data, taking into account one recharge and two barrier boundaries. The computed decline was then compared with the actual decline.

The pumpage from the Cambrian-Ordovician Aquifer in the Chicago-Joliet-Fox Valley area was grouped into six centers of pumping. Figure 37 shows the location of these centers and also the amount of pumpage from each in 1958. Pumpage from the Cambrian-Ordovician Aquifer, 1864 through 1958, was distributed among the six centers and further broken into step increments.

The six centers of pumping and the geohydrologic boundaries were drawn to scale on a map and the image wells were located. The distances between the observation point in the Lisle area and the six pumping centers and the image wells associated with the geohydrologic boundaries were scaled from the map.

The water-level decline at the observation point resulting from each increment of pumpage at each of the six pumping centers was determined, using the nonequilibrium formula (equation 2) to compute the effects of

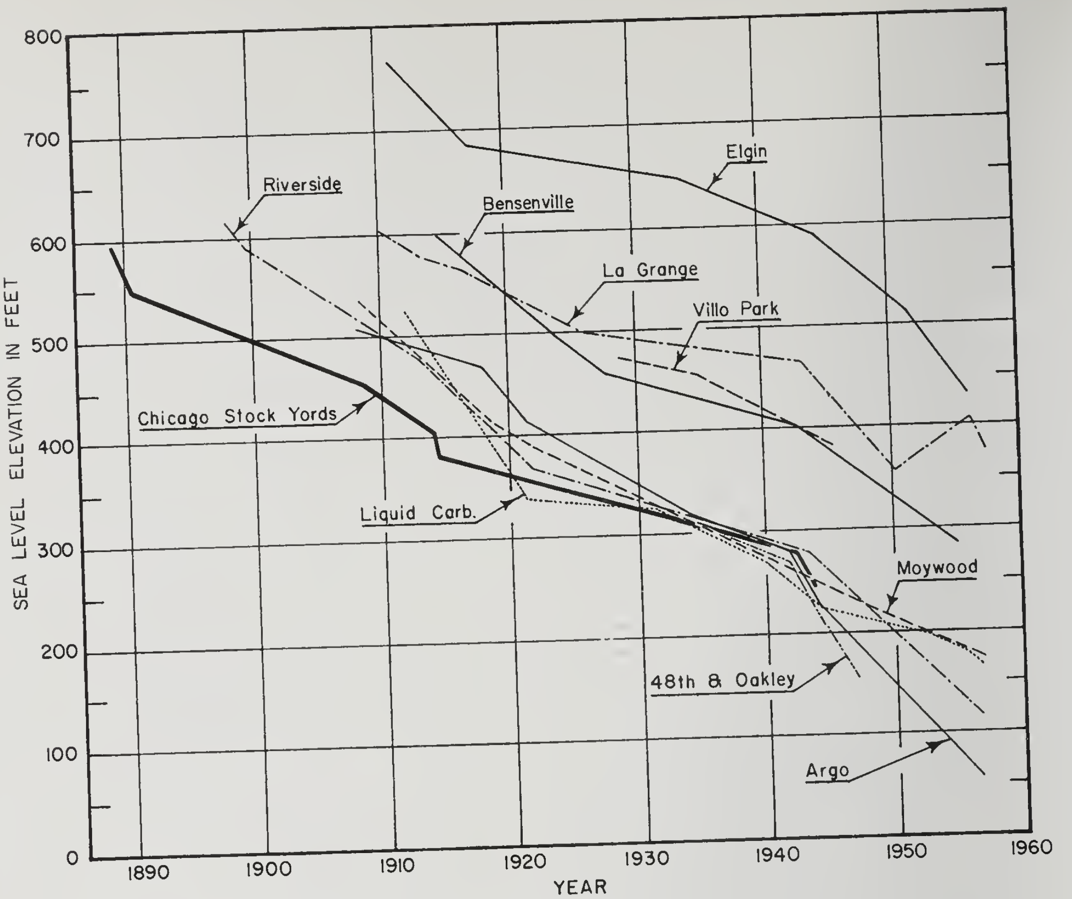


Fig. 38. Decline of artesian pressure in deep wells in the Chicago region for period of record.

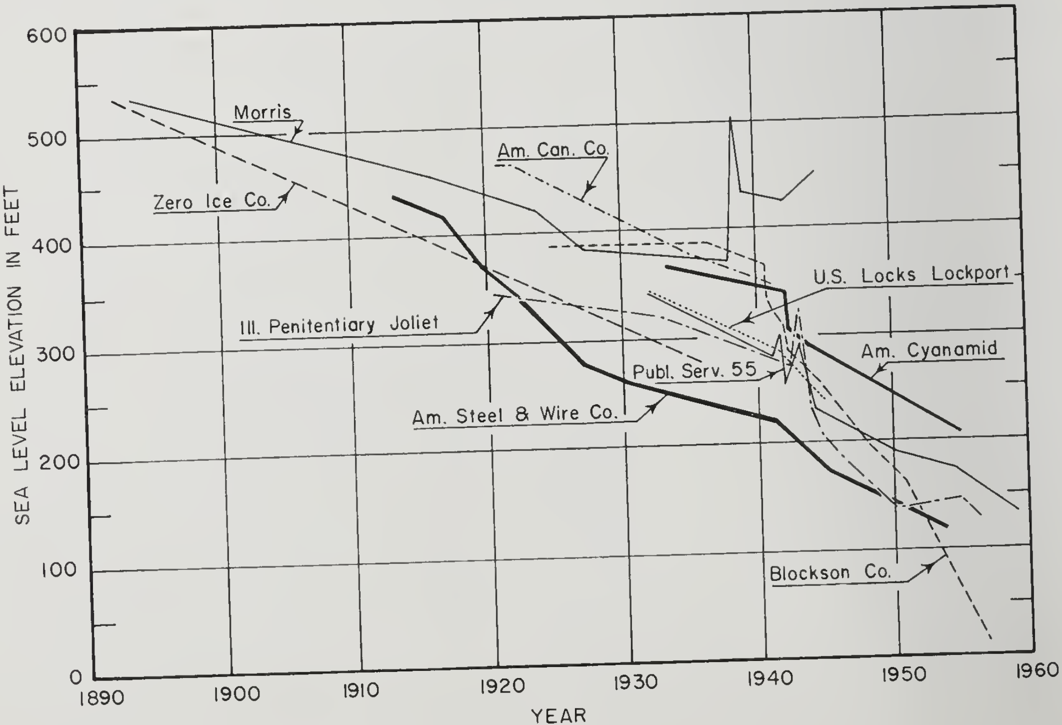


Fig. 39. Decline of artesian pressure in deep wells at Joliet for period of record.

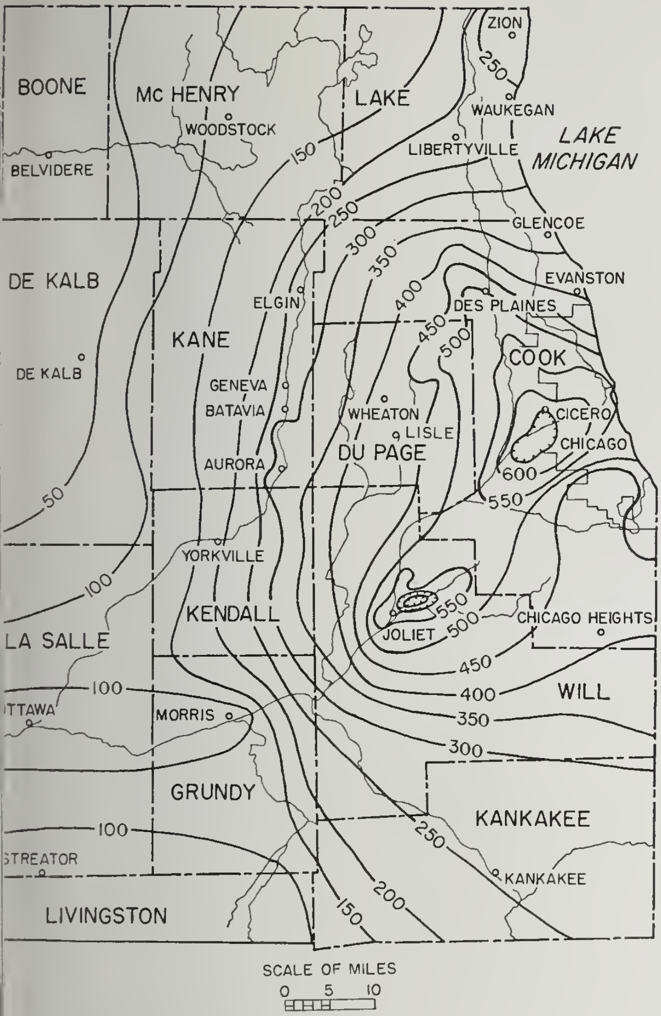


Fig. 40. Decline of artesian pressure in Cambrian-Ordovician Aquifer, 1864-1958.

e real and image wells. The computed nonpumping ater-level decline in the Lisle area resulting from past ithdrawals of water from each pumping center is given table 22.

The computed total decline in nonpumping water vel in the Lisle area, 1864 through 1958, is 450 feet. he actual decline, obtained from figure 40, is 420 feet. The computed decline is within about 7 percent of the actual decline. Even though the estimates of pumpage upon which calculations are based may be about 10 percent in error, the close agreement between computed and actual decline indicates that the hypothetical hydrologic system used closely describes the geohydrologic limits of the Cambrian-Ordovician Aquifer. It is believed that the hydrologic system may be used to predict with reasonable accuracy the effects of future ground-water development.

TABLE 22. COMPUTED NONPUMPING WATER-LEVEL DECLINE IN THE LISLE AREA

Pumping center	Fractional decline in feet
Chicago area	215.5
Joliet area	80.4
Elmhurst area	55.0
Des Plaines area	16.8
Elgin area	27.2
Aurora area	55.1
Total	450.0

POTENTIAL GROUND-WATER DEVELOPMENT AND ITS EFFECTS

Pumpage between the present time and any future date must be estimated before further declines in water levels in wells in the Cambrian-Ordovician Aquifer can be calculated. Graphs showing the pumpage from 1864 through 1958 in each of the six pumping centers in the Chicago-Joliet-Fox Valley area are given in figure 36. Pumpage in the centers from 1958 through 1980 was extrapolated taking into consideration the past rates of growth of pumpage. Assuming that the total pumpage from deep wells in the six centers will increase at fairly uniform rates, from 76 mgd in 1958 to about 92 mgd in 1980, the daily withdrawal from the Cambrian-Ordovician Aquifer in 1980 will be about 56 mgd.

Decline in water levels which may be expected on the basis of these assumptions, from 1958 through 1980, at Chicago, Joliet, Des Plaines, Elmhurst, Elgin, and Aurora, were calculated using the same principles outlined in the preceding section. Computed declines in each pumping center which are presented in table 23 are based on the assumption that the distribution of pumping remains the same and that the pumpage increases at the rates given in figure 36. It should be emphasized that the declines in water levels cited are nonpumping water levels. Pumping levels will decline about the same amount as the nonpumping water levels if the present rates of pumping from individual wells are maintained.

TABLE 23. COMPUTED FUTURE NONPUMPING WATER-LEVEL DECLINE, 1958-1980

Pumping center	Decline, 1958-1980 in feet	Predicted elevation, 1980, in feet
Chicago area	300	−250
Joliet area	220	−200
Elmhurst area	250	−100
Des Plaines area	300	−100
Elgin area	190	+300
Aurora area	250	+150

Considering the great complexity of ground-water conditions in the Chicago-Joliet-Fox Valley area, the accuracy of the predicted future declines in water levels is probably about ±15 percent.

By 1980 the Galena-Platteville Dolomite and the Glenwood-St. Peter Sandstone will be partially dewatered in parts of the Chicago-Joliet-Fox Valley area. The effects of partial dewatering on future declines in water levels in deep wells were estimated on the basis of available geologic and hydrologic data. It is important that collection of water-level and pumpage records be continued so that the effects of dewatering can be appraised. It may be necessary to recompute future declines in water levels within ten years on the basis of data collected under dewatering conditions.

Practical Sustained Yield of the Cambrian-Ordovician Aquifer

Aside from economic considerations and quality of the water, the sustained yield of the Cambrian-Ordovician Aquifer is dependent on the rate of recharge, on the coefficient of transmissibility, and on the spacing of wells and well fields. The quantity of water that can be withdrawn indefinitely from the Cambrian-Ordovician Aquifer depends in part upon the quantity of water that can be induced to enter the aquifer in recharge areas, which in turn is dependent on the rate at which precipitation enters the ground. It is estimated that the recharge area of the Cambrian-Ordovician Aquifer that affects the Chicago-Joliet-Fox Valley area is about 1200 square miles. If five percent of the average annual precipitation can be induced to infiltrate into the aquifer in recharge areas, a conservative figure, the total available water at the recharge areas would be about 100 mgd.

The coefficient of transmissibility of the Cambrian-Ordovician Aquifer is low. To transmit 25 mgd from recharge areas, at a hydraulic gradient of 20 feet per mile, would require a cross section 73 miles wide. The maximum hydraulic gradient that theoretically could be developed from recharge areas toward pumping centers in the Fox Valley, in the Chicago area, and in the Joliet area, without dewatering a portion of the Ironton-Galesville Sandstone and thereby greatly decreasing the coefficient of transmissibility of the Cambrian-Ordovician Aquifer, is about 44 feet to the mile. It is estimated that the width of the cross section through which movement from recharge areas could occur is about 85 miles. Computations made with equation (3) show that the maximum quantity of water that could be transmitted down-dip from recharge areas is about 65 mgd. This quantity is less than the estimated recharge rate. Thus the sustained yield of the Cambrian-Ordovician Aquifer depends on the coefficient of transmissibility and the maximum available gradient of the aquifer rather than on potential replenishment to the aquifer.

The maximum amount of water that can be transmitted from recharge areas cannot be developed unless water is withdrawn from a large number of uniformly and widely spaced wells. However, pumping has been and probably will continue to be concentrated in industrial and municipal centers. From a hydrologic standpoint concentrated pumping is inefficient, and development of the full capacity of the aquifer is impossible under existing and foreseeable pumping conditions. Thus, the practical sustained yield of the Cambrian-Ordovician Aquifer is less than the maximum amount of 65 mgd which can be transmitted down-dip from recharge areas.

As explained earlier in this report, considerable time passes before water levels reach approximate equilibrium and the full effects of pumping are realized. Computations made using the nonequilibrium formula (2), the image-well theory, and the hydrologic system previousl described indicate that, if the distribution and amoun of pumping, 43 mgd, from the Cambrian-Ordovicia Aquifer in the Chicago-Joliet-Fox Valley area remai indefinitely the same as in 1958, the nonpumping wate level at Chicago will eventually decline to an elevatio of about 550 feet below sea level under equilibrium con ditions. The nonpumping water level at Chicago woul be about 200 feet above the top of the Ironton-Galesvill Sandstone. Withdrawal rates could be slightly increase over those of 1958 without dewatering the Ironton Galesville Sandstone. Therefore, the practical sustaine yield of the Cambrian-Ordovician Aquifer is somewha greater than 43 mgd.

Computations made, taking into consideration dewatering, indicate that if the distribution of pumpag remains the same as in 1958 and the amount of pumpag from the Cambrian-Ordovician Aquifer increases to total of 46 mgd and then remains the same, the non pumping level in Chicago will eventually decline to position about 100 feet above the top of the Ironton Galesville Sandstone and at an elevation of about 65 feet below sea level. Pumping levels in wells, if th present rates of pumping from individual wells are mai tained, would be within a few feet of the top of the Iron ton-Galesville Sandstone. The pumping levels locall would be below the top of the Galena-Platteville Dol mite, the Glenwood-St. Peter Sandstone, the Prairie d Chien Series, Trempealeau Dolomite, and the Francon Formation, and these formations would be dewatere The dolomites and the Franconia Formation general are not very permeable, and dewatering of these fo mations would not appreciably decrease the coefficie of transmissibility of the entire Cambrian-Ordovici Aquifer. However, the Glenwood-St. Peter Sandsto has some permeability. The specific capacities of de wells would probably decrease on the average about percent as the result of dewatering the Glenwood-S Peter Sandstone.

The practical sustained yield of the Cambrian-Ord vician Aquifer is, therefore, estimated to be about mgd. The practical sustained yield of this aquifer w be developed when the total pumpage from deep wells the Chicago-Joliet-Fox Valley area is about 81 mgd. pumpage increases at the rates assumed in figure 36, t practical sustained yield will be exceeded in about 19 although equilibrium conditions will not yet have be achieved. The practical sustained yield of the Cambri Ordovician Aquifer could be increased by shifting ce ters of pumping to the west and by spacing wells greater distances.

SHALLOW DOLOMITE AQUIFERS

The shallow dolomite aquifers consist of Silurian ro in most of the region (note extent of Silurian in fig.

nd dolomites of the Maquoketa and Galena-Platteville Formations in the western part of the region.

Ground water occurs in joints, fissures, and solution hannels that range in size from hairline cracks to averns. The locations of these openings cannot be prelicted from the surface. Locally such openings may be artly filled with silt and clay which may be troublesome n development of wells. However, the upper part of the lolomite is usually the most productive. The thickness f the Silurian rocks ranges from a feather edge in the vestern part of the area to more than 450 feet in the outheast (fig. 27). Silurian rocks are the primary ource of water for most household and farm wells and or many municipal and industrial wells. Many of the ells penetrate only the upper part of the dolomite, as hown in figure 41. Usually only the municipal and ndustrial wells penetrate the entire thickness of the quifer.

The daily pumpage during 1957 from wells penetrating he shallow dolomite aquifers is given in table 13. The reater part of this pumpage occurs in Cook and DuPage ounties. Many high capacity wells have been conructed in parts of these counties where many crevices ave been encountered.

A study was made of the specific capacities of municial and industrial supply wells in the shallow dolomite Cook, DuPage, Kane, Lake, McHenry, and Will ounties. Specific-capacity data obtained from the files the State Water Survey, for 154 wells, are given in table 24. The data for the counties are summarized in table 25.

Specific capacities listed in the tables range from 0.1 to 550 gpm per foot. Wells in DuPage County have the highest average specific capacity (54.5 gpm per foot), and wells in Lake County have the lowest average specific capacity (5.0 gpm per foot). The average specific capacity per foot of penetration of wells in DuPage County is much greater than that of wells in other counties.

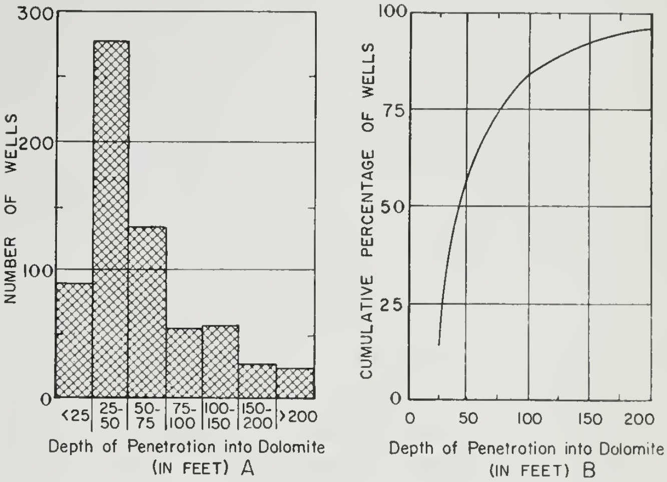


Fig. 41. Depth-frequency histogram (A) and depth-cumulative percentage curve (B) of wells completed in shallow dolomite in 17 townships in Will and Cook Counties.

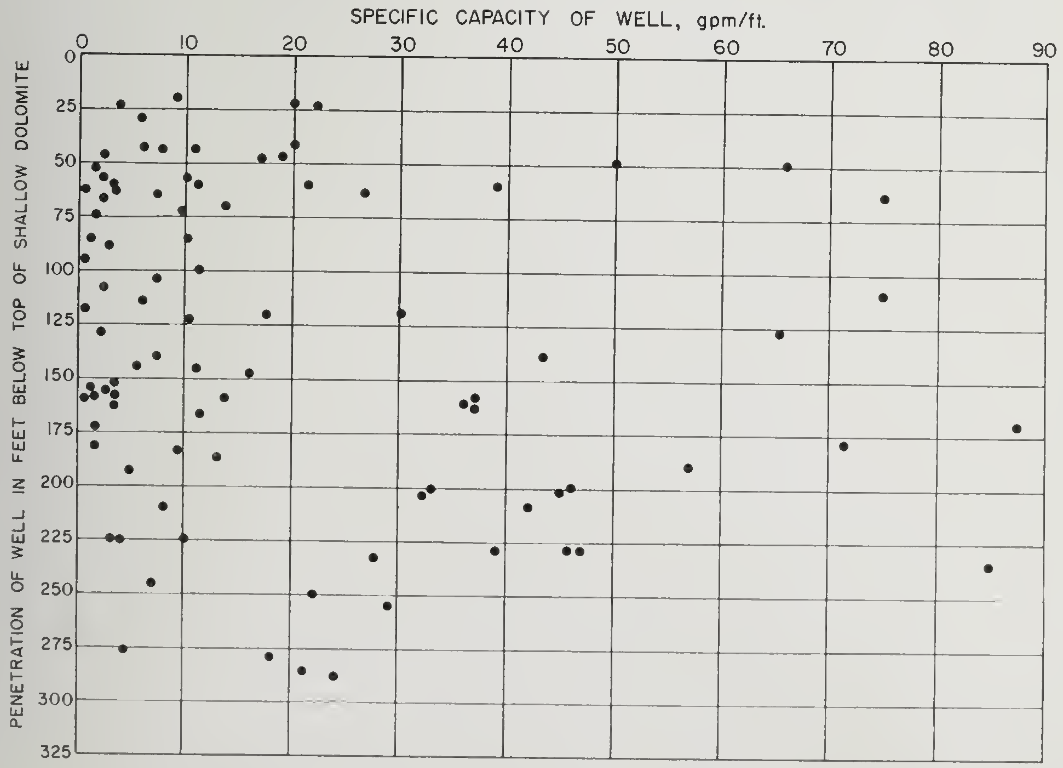


Fig. 42. Penetration versus specific capacity of wells in shallow dolomite aquifers.

TABLE 24. SPECIFIC-CAPACITY DATA FOR WELLS IN SHALLOW DOLOMITE

Location and owner of well	Well No.	Depth of well *(feet)*	Diameter of casing *(inches)*	Penetration of well below top of aquifer *(feet)*	Date of test	Nonpumping level *(feet)*	Pumping rate *(gpm)*	Draw-down *(feet)*	Specific capacity *(gpm/ft)*
Cook County									
Arlington Heights									
Village	1	140	10	23	1946	25	240	61.5	3.9
State Highway Garage	1	172			1951	25	37	16	2.3
Jockey Club	3	761			1946	37	86	150	0.6
National Mortgage Co.	1	201			1949	33	120	117	1.0
Barrington									
Village	1	305	12–10	60	1943	66.1	200	9.3	21.5
Village	2	210	16	60	1946	52	400		
Barrington Woods		250			1953	44	22.3	161.5	0.13
Village	1	305	12–10	60	1933	60.8	350	3.7	96
Village	2	210	16	60	1929	53.5	540	13.8	39
Bartlett									
Village	1	200	8	49	1923	33	265	4	66
Village	1	200	8	49	1946	37	200	4	50
Berkeley									
Village	2	151	10	47	1930	44	150	8	19
Village	2	151	10	47	1944	60	200	12	17
Chicago									
Chicago-United Air Lines	1	410			1946	49	108	67	1.6
Chicago Heights									
City	15	193	24	158	1946	88	1000	27	37
City	18	251	26	209	1941	Flowing	1650	39	42
City	19	330		288	1946	20	400	17	24
City	21	203	30–24	161	1945	22	870	24	36
City	21	203	30–24	161	1945	22	1670	45.5	37
City	22	270	33–22	200	1946	26	960	21	46
City	23	260	30–24	202	1946	33.5	1800	55	33
City	23	260	30–24	202	1956	33.5	1270	28	45
American Locomotive Co.	3	222			1942	56	1150	2.1	550
Flintkote Co.	3	300			1946	106	310	107	2.9
Penn Salt Co.	1	215	16–266		1954	7	108		
Victor Chemical	3	433			1947	37	118	215	0.5
Victor Chemical	4	250			1947	56	347	111	3.1
Flossmoor									
Village	1	275	10	210	1945	90	300	20+	
Village	2	351	12–10	286	1945	40	425	20	21
Village	3	467	16–14–12	402	1941	64.5	395	89.5	4.4
Village	1	275	10	210	1940	47	300	38	8
Glencoe									
H. Levy	1	206			1937	72	27	13	2.1
Hillside									
Village	2	180	8–6	158	1937	35	40	25	1.6
Hinsdale									
Suburban Sanatorium	1	357			1952	39	322	112	2.9
Homewood									
Village	1	252	12–10	182	1923	29	170	22	7.7
Village	Tw 1-46	460	6	351	1945	29	210	59	3.5
Village	1	252	12–10	182	1945	34	245	133	1.8
Village	3	436	22	364	1945	35	250	242	1.0
Dixmoor	4	226	10	162	1946	17	240	73	3.3
Oaklawn Cemetery	2	302			1946	42	175	16	11
Ravisloe CC	3	420			1953	41	530	38	14
La Grange									
Cornet Development	1	420			1953	81	367	49	7
Lyons School No. 105	1	377	13–154		1951	54	90	86	1
La Grange Park									
M. Magisano	1	327			1950	66	38	7	5.4
Lambert									
Univ. of Chi. Exp. Station	1	308			1944	153	65	14	4.6
Lemont									
Coghill CC	2	173			1941	71.7	127	5.3	24.0
Fournier Inst.	1	370			1947	104	390	12.5	31.2
Matteson									
Village	1	282	10		1945	14	200	8	25
Public Service Co.	1	156			1948	27	313	7.5	41.7
Mt. Prospect									
Village	1	200	12–8	105	1937	36	160	103	
Village	2	210	12–10	108	1945	45	100	40	2.5
Northfield									
Woods Subdivision	1	300			1954	55	60	179	0.3
Test Well	1	316			1947	19	133	119	1.1
Oak Forest									
Village	2	297			1952	15	520	55	9.4

TABLE 24. (Continued)

Location and owner of well	Well No.	Depth of well *(feet)*	Diameter of casing *(inches)*	Penetration of well below top of aquifer *(feet)*	Date of test	Nonpumping level *(feet)*	Pumping rate *(gpm)*	Draw-down *(feet)*	Specific capacity *(gpm/ft)*
ook County (continued)									
Oak Lawn									
School District No. 111		215			1945	54	76	34	2.2
School District No. 111		286			1948	40	30	103	0.3
School District No. 220	1	298			1942	49	49	34	1.4
School District No. 220	2	375			1948	60.5	61	30	2.0
Orland Park									
Village	1	329	6	119	1938	40	238	8	30
Capitol Dairy	1	355	6	295	1943	12	100	0	
Palatine									
Village	5	209	12	67	1945	2	210	96	2.2
Park Forest									
Village	2	300	24–15	205	1947	57.5	1150	12	96
Village	3	350	24–16	255	1948	41	1045	36.5	29
Village	5	345	24–17	250	1953	50	575	5	115
Commercial Well	4	345	12	250	1952	39	1020	46	22
Prospect Meadows		201			1950	33	135	68	2
Stickney									
Nat'l. Alum. Co.	1	393			1936	79.5	84	105.5	0.8
Nat'l. Alum. Co.	2	233			1937	85	63	87	0.7
Stone Park									
Village	1	291	12–11	245	1943	172	86	13	7
Sacred Heart Sem.		250			1940	173	57	6.5	9
Thornton									
Village	2	408	12	225+	1946	237	120	33	4
Village	3	250	8	225	1944	97	100	10	10
Tinley Park									
State Hospital	1	491	24–20	347	1952	23	685	143	5
State Hospital	1	491	24–20	347	1952	23	625	100	6
State Hospital	3	515	28–19	347	1951	14	680	80	8.5
Western Springs									
Village	1	385	16	350	1946	56	550	24	23
Village	2	313	15	278	1946	67	500	27.5	18
Wheeling									
Village	1	200	12–10	140	1926	15	150	20	7.5
Page County									
Addison									
Village	1	155	10	65	1916	18	150	2	75.0
Belmont	2	295		235	1954	84	340	4	85.0
Clarendon Hills									
Village	1	295			1953	102	210	24	8.8
Village	2	250	12	110	1947	113	300	4	75.0
Village	3	354	12	203	1945	91	385	12	32.1
Downers Grove									
Village	Lee	250	30	178	1947	46	860	12	71.5
Village	Park	291	30	127	1945	96	980	15	65.4
len Ellyn									
Village		310	8	145	1916	42	500	93	5.4
Village	2	352	12	145	1947	76	750	68	11.0
Village	3	422	18	123	1947	98	750	72	10.4
Village	Park	325			1936	17	352	33	10.8
Village	4	422			1954	85	995	27	36.8
insdale									
Village	1	209	12	149	1924	17	520	3	176
Village	2	271	20	229	1924	37	1100	24	45.8
Village	2	271	20	229	1942		1460	14	104
Village	3	210			1943		1400	11	124
isle									
(St. Procopius 2)		245			1935	62	218	15	14.5
ombard									
Village	1	84	8	24	1947	10	465	21	22.1
Village	3	175	20	103	1948	10	600	80	7.5
aperville									
City	4	178	30	134	1943	11	1000	23	43.5
City	5	190	30	158	1947	12	560	41	13.7
City	6	202	27	172	1947	13	285	166	1.7
oselle									
Village	1	182	10	43	1926	37	110	14	7.9
Village	2	183		43	1953	47	372	60	6.2
lla Park									
Village	3	285	8	225	1949	55	257	82	3.1
Village	4	251	12	193	1949	60	176	36	4.9
est Chicago									
City	2	322	12	233	1947	82	500	18	27.8
City	3	310			1950	73	510	41	12.4
estmont									
Village	2	313	16	190	1938	101	600	1.2	500
Village	3	302	17	167	1936	122	320	28	11.4

TABLE 24. (Continued)

Location and owner of well	Well No.	Depth of well (feet)	Diameter of casing (inches)	Penetration of well below top of aquifer (feet)	Date of test	Nonpumping level (feet)	Pumping rate (gpm)	Draw-down (feet)	Specific capacity (gpm/ft)
Wheaton									
City	4	350	18	64	1946	44	985	37	26.8
McHenry County									
Cary									
Village		300	10	146	1947	30	113	70	1.6
Crystal Lake									
City		280	10	20	1947	107	415	46	9.0
Nat. Grain Yeast		319			1940	106	140	63	2.2
Pure Oil Co.		423			1948	74	75	85	0.9
Fox River Grove		145	13	43	1947	9	250	23	10.9
Kane County									
Aurora									
Hanson Greenhouse	1	103	8	85	1937	7	25	21	1.2
Marviray Manor	1	300		85	1946	27	50	5	10.0
Batavia									
Campana	1	281	10	60	1945	37	280	90	3.1
Geneva									
Burgess Norton No. 2	2	220		74	1950	50	200	120	1.7
Montgomery									
Village	1	175	10–8	23	1947	54	100	5	20.0
North Aurora									
Village	West Well	190		57	1953		20	2	10.0
Lake County									
Fox Lake									
Chain O'Lakes St. Pk.	1	270			1940	54.5	40	97	0.4
Half-Day									
E. Ryerson, Jr.	1	200			1940	6	25	119	0.2
Lake Zurich									
Village	3	443	6	65	1949	135.5	209	29	7.2
Mt. St. Joseph	1	400			1949	106	121	74	1.6
Libertyville									
Village	5	251	24-16	64	1935		442	129	3.4
Village	7	287	12	114	1947	15	495	82	6.0
Village	5th Ave	250		95	1950	7	96	161	0.6
Village	TW	215		58	1950	33	210	19	11
Village		227		70	1951	39	590	43	13.7
Mundelein									
Village	2	285	12	46	1930	64	125	57	2.2
Village	3	213	10	57	1947	90	125	60	2.1
Round Lake									
Village	1	350	6	120	1945	40	175	10	17.5
Village	2	359	10	89	1945	51	288	107	2.7
Beach	1	342		117	1948	41	100	158	0.6
Park	1	279	6	29	1939	46	150	26	5.8
Park	3	313	10	53	1944	46	100	74	1.4
Wauconda									
Village	1	230		73	1939	39	270	28.5	9.5
Village	2	257		100	1939	67	400	36	11.1
Zion									
City	2	220	10–8	63	1932	12	50	105	0.5
Will County									
Channahan									
Div. of Waterways	1	269			1942	47	7	88.5	0.1
Canal State Park	1	266			1942	60	35	15.2	2.3
Crete									
Village	1	192	10	42	1945	48.5	169	8.5	20.0
Village	2	264	12–10	184	1924	45	300	32	9.4
Elwood									
Arsenal	G3	388		155	1941	21	246	92.5	2.7
Arsenal	G3A	137			1941	21	241	87.7	2.8
Batch Plant	3	187		155	1941	18	100	35.0	2.9
Batch Plant	2A	100			1941	8.5	215	60.0	3.6
Mokena									
Village	2	225	8	190	1920	67	57	1	57
Monee									
Cardox Corporation	2	408	20–18–17¼	277	1945	59	195	43	4.5
New Lenox									
Suburban Water Co.	1	378		155	1948	53	65	103	0.6
Lincoln Way School	1	356		155	1953	30	120	107	1.1
Plainfield									
Village	1	200	26–16–15	158	1929	12	200	61.3	3.3
Village	2	201	26–16–15	153	1929	10	200	61.5	3.3
Steger									
Village	1	318	12	171	1945	43	350	4	87.6

TABLE 25. SPECIFIC-CAPACITY DATA FOR WELLS IN SHALLOW DOLOMITE, SUMMARY BY COUNTY

nty	No. of wells for which data are available	Average depth of well (*feet*)	Average dia. of well (*inches*)	Average penetration (*feet*)	Average pumping rate (*gpm*)	Average specific capacity (*gpm/ft*)	Range of specific capacity (*gpm/ft*)	Average specific capacity per foot of penetration (*gpm/ft*)
k	77	295	14	194	393	27.8	550–0.1	0.14
?age	30	265	17	148	593	54.5	500–1.7	0.37
ıe	6	212	9	64	113	7.7	20.0–1.2	0.12
e	20	288	10	79	207	5.0	17.5–0.2	0.06
Ienry	5	293	11	70	199	7.8	16.1–0.9	0.11
l	16	262	12	164	169	13.1	87.6–0.1	0.08

graph (fig. 42) of specific capacity versus penetra- of well below the top of the shallow dolomite was pared using the data in table 24, which is based pri- ily on the larger municipal and industrial wells. graph indicates that there is no definite relation veen depth of penetration and the specific capacity a well. The data are widely scattered because the ribution of the water-bearing openings in the shallow mite is not uniform from depth to depth and from e to place. Most of the data are aligned vertically he range of specific capacity from 0–20 gpm per foot cating that the water-bearing openings in the shal- dolomite are normally more abundant and larger he upper part of the aquifers and that the specific icity of a well is not greatly increased with large hs of penetration.

ough estimates of the coefficient of transmissibility he shallow dolomite were made by substituting in non-equilibrium formula (2) an artesian coefficient orage, and well-construction data and average spe- capacities from table 25. Based on average specific- city data, the coefficient of transmissibility of the ow dolomite averages about 100,000 gpd per foot in age County, 52,000 gpd per foot in Cook County, 0 gpd per foot in Will County, 14,000 gpd per foot ane and McHenry Counties, and 9,000 gpd per foot ake County. The estimated average coefficient of missibility of the shallow dolomite in DuPage, Cook, Will Counties is much greater than the average co- ent of transmissibility of the Cambrian-Ordovician fer in these counties.

e shallow dolomite immediately underlies and is ly recharged by precipitation through the glacial sits.

e water levels in the dolomite vary greatly from to time and place to place; however, at no location re any apparent permanent decline. The differing levels are caused by pumpage and by variations harge from precipitation. A typical example is at go Heights where water levels are extremely re- ive to fluctuations in precipitation as shown in 43. The water levels rise when precipitation is normal and fall when precipitation is below l.

harge by individual storms has been observed by le water-level rises in wells. Such variation results a number of factors, such as permeability of the ing glacial drift, degree of crevices connecting with the overlying drift, and the extent of saturation produced locally by an individual storm.

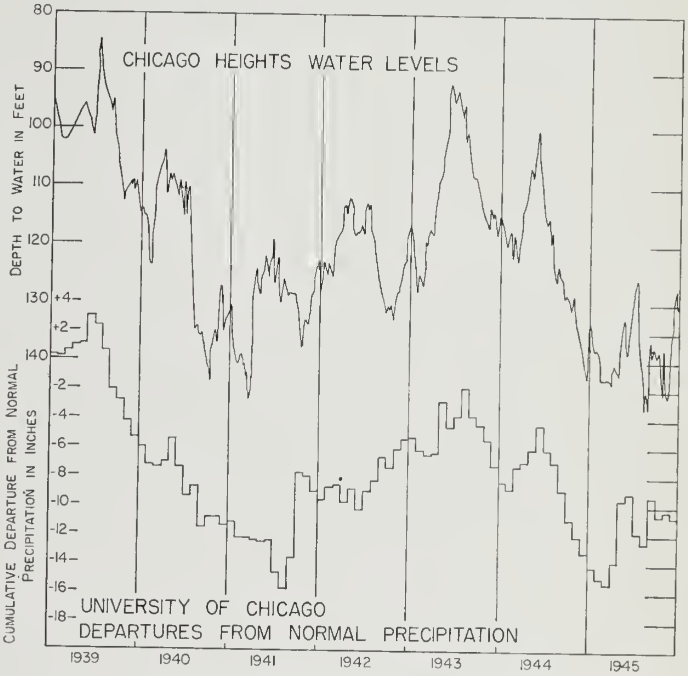


Fig. 43. Water levels compared with departure from normal precipitation at Chicago Heights.

GLACIAL DRIFT AQUIFERS

Numerous rural and residential water supplies, but only a few large supplies, are drawn from the glacial drift. The largest supplies are withdrawn from the fill of the buried Hadley Valley northeast of Joliet. The city of Joliet constructed five gravel wells that produce 650 gpm each. Several other municipal and industrial installations that obtain water from the drift are located in the region, none of which is overpumping the aquifer at the present time.

Specific-capacity data for municipal and industrial wells in the glacial drift aquifers throughout northeastern Illinois are summarized in table 26. This tabulation indicates that the range in specific capacity is from 2.1 to 66 gpm per foot and averages about 12 gpm per foot. The average depth and diameter of wells is 126 feet and 12 inches respectively, and the average aquifer thickness is 107 feet. Of the 40 wells listed only 4 were unscreened. The average length of screen used in the

36 screened wells was 25.5 feet. The data in table 26 indicate that the coefficient of transmissibility of the sand and gravel aquifers in northeastern Illinois ranges between 3,400 and 100,000 gpd per foot and averages 25,000 gpd per foot.

POTENTIAL YIELD OF SHALLOW AQUIFERS

The glacial drift and shallow dolomite aquifers yielded more than 75 mgd of ground water in 1957, over half of the pumpage of the region. Of the 75 mgd, 41.2 mgd were from wells finished in shallow dolomite aquifers and 14.2 mgd were from wells finished in glacial drift aquifers (table 13). The remaining 20 mgd were obtained mainly from Silurian age dolomite through deep wells that were uncased or were ineffectively cased below the drift (see section on Quantity of Water Derived from Silurian Age Dolomite and Mt. Simon Aquifer and fig. 37).

The most concentrated pumpage from the shallow aquifers in 1957 (table 14) occurred in southeastern DuPage County and adjoining Cook County around La Grange (fig. 28), where most of the wells are finished in Silurian age dolomite.

Figure 44 shows hydrographs of water levels in the shallow aquifers. Most of the hydrographs are from wells in the area of concentrated pumpage in southeastern DuPage County. Although the water levels vary greatly from time to time and from place to place, the hydrographs indicate no general or permanent decline in water levels.

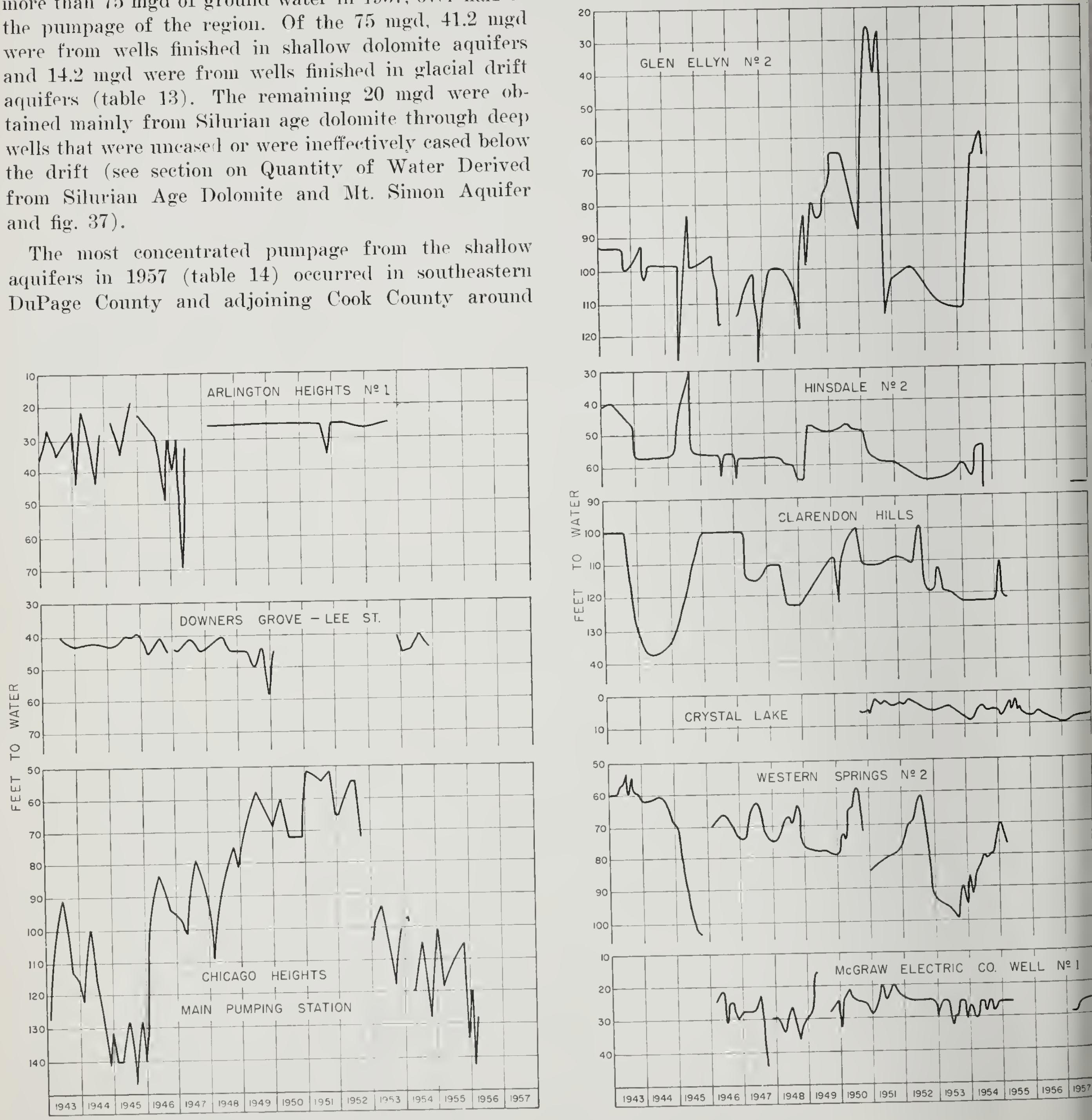


Fig. 44. Hydrographs of water levels in the shallow aquifers.

TABLE 26. SPECIFIC-CAPACITY DATA FOR WELLS IN GLACIAL DRIFT

Location and owner of well	Well No.	Depth of well *(feet)*	Diameter of casing *(inches)*	Screen length-dia. *(ft. - in.)*		Thickness of aquifer *(feet)*	Date of Test	Non-pumping level *(feet)*	Pumping rate *(gpm)*	Drawdown *(feet)*	Specific capacity *(gpm/ft)*
Lake County											
Antioch											
Village	2	226	10	20		70	1946	39	200	22	9.1
Fox Lake											
Village	2	135	16	16	15	215	1941	35.7	284	4.3	66.0
Gurnee											
Hoag Farm	1	145	12	25		110	1949	31.5	289	77	3.8
Island Lake											
Village	19–u	116	10	24	10	150	1940	29	503	11	46.0
Village	K–9	87	8	10	7	150	1943	9	280	16	17.5
Lake Villa											
Village	1	167	12–10	26	10	233	1938	55	154	4.5	34.2
Libertyville											
Village	6	83	8	30	8	167	1943	28	380	14	27
Fould's Milling	2	202	8	14	8	190	1945	7	275	84.5	3.3
Milburn											
Traer Well		190	12	17		90	1948	42	127	13	9.8
Mundelein											
Village	3	213	10	None			1946	90	125	60	2.1
Round Lake											
Village	2	225	10	None		56	1945	51	290	107	2.7
McHenry County											
Crystal Lake											
City	Tw 1–48	45				250	1948	15	307	28.7	10.7
City	3	48	12	10	10	25	1948	17.8	250	17.8	14
Harvard											
City	3	71	14	15			1947	17	600	50.0	12
City	4	69	26	20		120	1946	17	375	29.0	12.9
Huntley											
Village	2	74	6			55	1947	23	100	3.0	33.3
Village	3	69	10			52	1953	22	317	11.0	28.8
Marengo											
City	2	21	240			19+	1947	7.3	150	4.3	34.9
McHenry											
City	6	104	24	20		95+	1947	9	400	22.0	18.2
Richmond											
Village	1	170	10	10	14	140	1947	23	150	42.0	3.6
Woodstock											
City	1	196	13–24	80		155	1921	49.5	648	37.5	17.3
City	2	207	13–24	70		155	1947	57.0	1000	46.0	21.7
City	3	198	18	50		155	1947	56.5	1150	34.5	33.4
ane County											
Burlington											
Village		111	6	15			1941	33.0	40	5.0	8
Elburn											
Village	2	153	8–10	11		68	1947	85	75	20	3.7
Elgin											
St. Charles		105	16			92	1945	13.0	950	60.0	15.8
N. State		43	25	18		27	1946	28.5	215	5.5	39
Crighton		53	25	12		34+	1946	8.3	200	23.7	8.5
Ill. Tool Works		249					1944	23.5	237	21.5	11
Sugar Grove											
Village	1	104				135	1948	49.6	106	5.8	18.3
ll County											
Joliet											
Hadley Valley	Tw 2	114	6	17	6	32	1945	45.0	180	45	4
Hadley Valley	Tw 5	103	6	10	6	86	1945	16.5	169	72.5	2.3
Hadley Valley	Tw 6	90	6	20	6	57	1946	33.0	270	38	7.1
Hadley Valley	Tw 7	97	6	30	6	60	1946	37.0	330	12	27.5
Hadley Valley	Tw 8	145	6	30	6	94	1945	51.0	335	12.5	27
Hadley Valley	Tw 1	175	10	None		115	1943	19.5	268	24.5	10.9
Hadley Valley		85	18	27	18	93	1950	37.3	420	6.6	63.7
Hadley Valley		94	18	35	18	112	1950	18	967	43.0	22.5
Hadley Valley		115	18	40	18	94	1950	36	1130	58	19.5
Hadley Valley		135	6	35	6	113	1949	22	260	14	18.6

Therefore, the present withdrawal of 75 mgd is within the potential yield of the shallow aquifers. The fact that there has been no decline even in the area of heaviest pumpage indicates that the potential yield of the shallow aquifers probably is considerably larger than the present withdrawal.

The pumpage per square mile of 68,400 gpd in DuPage County is equivalent to a yearly infiltration from precipitation of 1.43 inches or about 4 percent of the average annual total. Actual infiltration of precipitation must be greater than 1.43 inches since water levels have not declined and ground water is discharged as base flow of streams in the area. It has been estimated for the state as a whole that about 10 to 12 percent of the annual precipitation reaches the ground-water reservoir, and it is reasonable to believe that recharge in the Chicago region is within this order of magnitude.

The shallow aquifers are the most likely sources to investigate for additional ground-water supplies. These aquifers are more readily recharged than the deep aquifers and locally have coefficients of transmissibility considerably higher than the Cambrian-Ordovician Aquife The present yield of the shallow aquifers is well withi their potential yield, whereas, withdrawal of water fro the deep aquifers has already approached the calculate sustained yield.

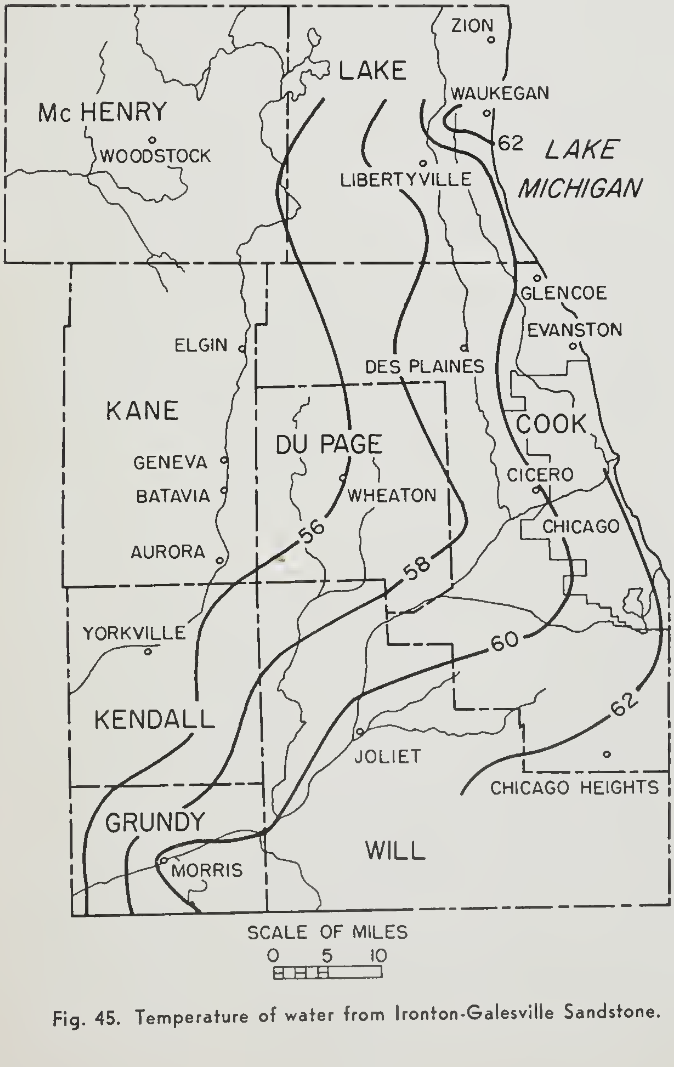


Fig. 45. Temperature of water from Ironton-Galesville Sandstone.

Additional studies of precipitation, infiltration, ru off, aquifer characteristics, and aquifer distribution ar needed before the potential yield of the shallow aquifer can be determined quantitatively.

WATER QUALITY

Many of the approximately 1600 mineral analyse which have been made in the Chicago region are give in State Water Survey Bulletins 34, 35, 36, 40 and Supplement 1 to Bulletin 40. Typical analyses are given i Appendix A (Larson, 1957, p. 11–15).

Ground waters in the Chicago region vary in qualit between the different producing aquifers and also within individual aquifers at different geographical location Below an elevation of 1300 feet below sea level, groun water in the deep aquifers is too highly mineralized fo most purposes.

This section discusses temperature and the miner content of the waters from a) the drift and shallo dolomite aquifers, b) Cambrian-Ordovician Aquifer, an c) the Mt. Simon Aquifer.

The quality of water obtained from any well depend not only on the geological formations penetrated durin drilling, but also on the geographical location, the relative productivity of the various formations, the relativ artesian head of the various formations, and often on th rate of pumping as well as the idle period and time c pumping prior to collection of the sample. In som areas, open and unplugged wells may permit water fro one aquifer to migrate to another aquifer.

TEMPERATURE

The temperature of water from 213 drift and dolomit wells of 100 to 300 feet depth in the region average 51.6°F. with 71 percent of the temperatures rangin from 50.5°F. to 52.5°F. Temperatures above 52.5°F were noted at 34 wells with a maximum of 54°F., an below 50.5°F. at 27 wells with a minimum of 46°F. I may be assumed that these "abnormal" temperatur were due to the entrance of water from depths less tha 100 feet during warm or cold seasons respectively.

The temperatures of water from wells entering th Cambrian-Ordovician Aquifer are influenced by th proportions of water entering the well from the shallo drift and dolomite aquifers. The following observatio have been made on wells which were constructed in suc a way as to case out and seal with cement grout all wate from above the base of the Maquoketa Formation. Certain inconsistencies, even at many of these wells, ma be due to the presence of water from shallow aquifers o the deeper Mt. Simon Aquifer by entrance to the we through the crevices in the Trempealeau or Galen Platteville Formations from nearby wells.

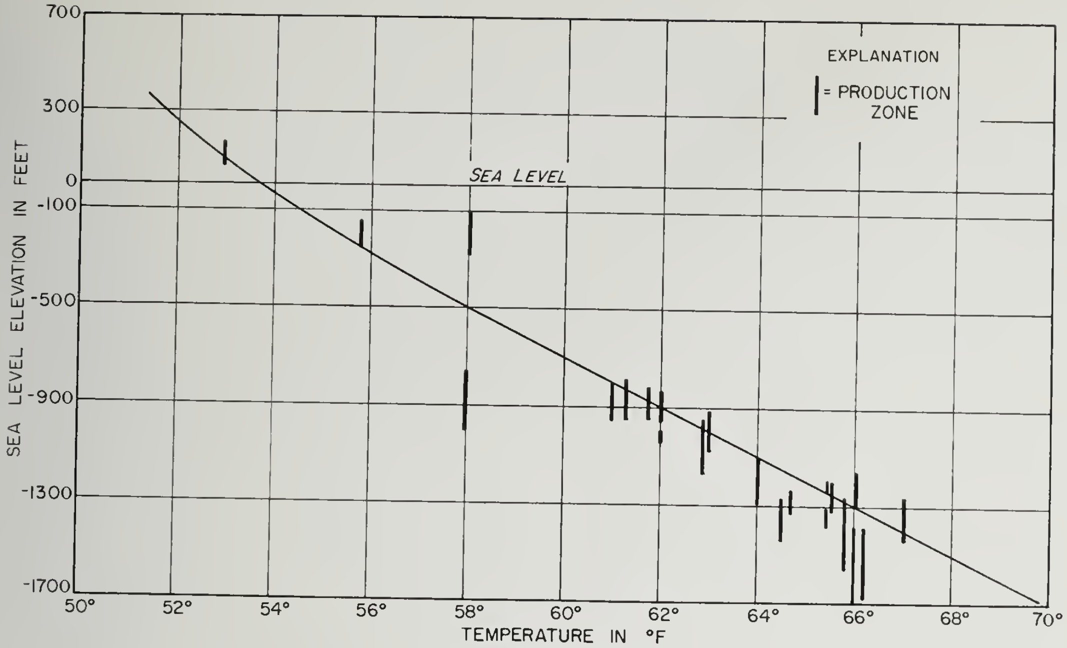


Fig. 46. Elevation versus water temperature in the deep aquifers.

Waters from the Glenwood-St. Peter Sandstone range temperature from 53°F. in Kendall County (elevation 5 feet to 0) to 56°F. in the vicinity of Mt. Prospect 0 feet above to 100 feet below sea level) and 58°F. ar the lake shore in Lake County.

Waters from the Ironton-Galesville Sandstone (fig.) range in temperature from about 55°F. in the Fox lley to 59–61°F. near Joliet and the southern and stern boundary of Chicago. At Chicago Heights and ar the Indiana state line the temperatures are about °F. The temperatures of these waters depend not only the elevation of the Ironton-Galesville Sandstone (fig. A) but also on the proportion of water contributed by Glenwood-St. Peter Sandstone. The sandstones in s region dip to the east and south (figs. 21A and 22A) d figure 45 indicates the temperatures of the waters m the Ironton-Galesville Sandstone with little or no tribution from the Glenwood-St. Peter Sandstone. In western third of the area the data are not sufficient greater definition, but such water is of less than F. temperature and in isolated areas may be as low perhaps 53° F.

The temperatures of water from the Ironton-Galesville ndstone in the western third of the region are lower n that indicated by the "normal" gradient of tem- ature with depth or elevation (fig. 46). It therefore ears probable that the Cambrian-Ordovician Aquifer y have become cooled by inflow of water from the harge areas to the west.

Water from the Mt. Simon Aquifer appears to increase emperature by about one degree per 100 feet of addi- nal depth from 66°F. at elevation 1300 feet below sea l as shown in figure 46. Again the temperature at well discharge depends largely on the amount of ding with water from shallower aquifers.

MINERAL QUALITY

Shallow Drift and Dolomite Aquifers

Waters from glacial deposits and the shallow dolomites are generally considered as associated. This is due to the creviced structure and eroded top of the dolomite which permits movement of water to as well as from the overlying drift. No attempt has been made to distinguish between their qualities.

In and near McHenry and northern Kane County many waters are characterized by the absence of sulfate. The occurrence of methane gas is not infrequent. These are essentially bicarbonate waters having an alkalinity greater than the hardness and almost equal to the total mineral content. About 80 percent of approximately 60 samples contained more than 0.3 ppm iron. The hardness ranges from 100 to 450 ppm with a median of 275 ppm, with half the samples ranging from 225 to 325 ppm.

Waters of less than 100 ppm hardness are found only along the eastern edge of the region and near the Indiana border toward the southern end of Cook County. A number of areas of exceptionally hard water, more than 1000 ppm, are indicated. These waters occur in a band extending from southwestern Lake County through Western Springs and Palos Park to Chicago Heights, coinciding roughly with the upland produced by the Valparaiso moraine (fig. 5). Geographic distribution is shown in figure 47.

Cambrian-Ordovician Aquifer

Waters from the Glenwood-St. Peter and Ironton-Galesville Sandstones are in general of similar mineral quality. As the major availability and use of water is from the Ironton-Galesville Sandstone, this discussion is concerned primarily with this part of the Cambrian-Ordovician Aquifer.

The mineral quality of the water from the Ironton-Galesville Sandstone is relatively uniform over an extensive area in the western two thirds of the region and generally exemplified by that at Montgomery near Aurora (Appendix A) (fig. 48). The mineralization increases eastward at an increasingly rapid rate as the formation becomes deeper (fig. 21A). From the eastern edge of DuPage County and southward from Joliet, the hardness increases from 290 to 800 ppm (fig. 48), the sulfate content increases from 100 to 800 ppm (fig. 35), and the chloride content increases from 25 to 400 ppm (fig. 49), at the northern end of the Indiana state line.

The quality of water at individual wells may be influenced by the proportion of water from the Glenwood-St. Peter Sandstone present in the sample. The thickness of the Glenwood-St. Peter Sandstone may range from 100 to 650 feet (fig. 22B); it locally yields abundant water and thereby influences the proportions of minerals in the water. In general, water from the Glenwood-St. Peter Sandstone tends to have a chloride content a hardness higher than water from the Ironton-Galesvill

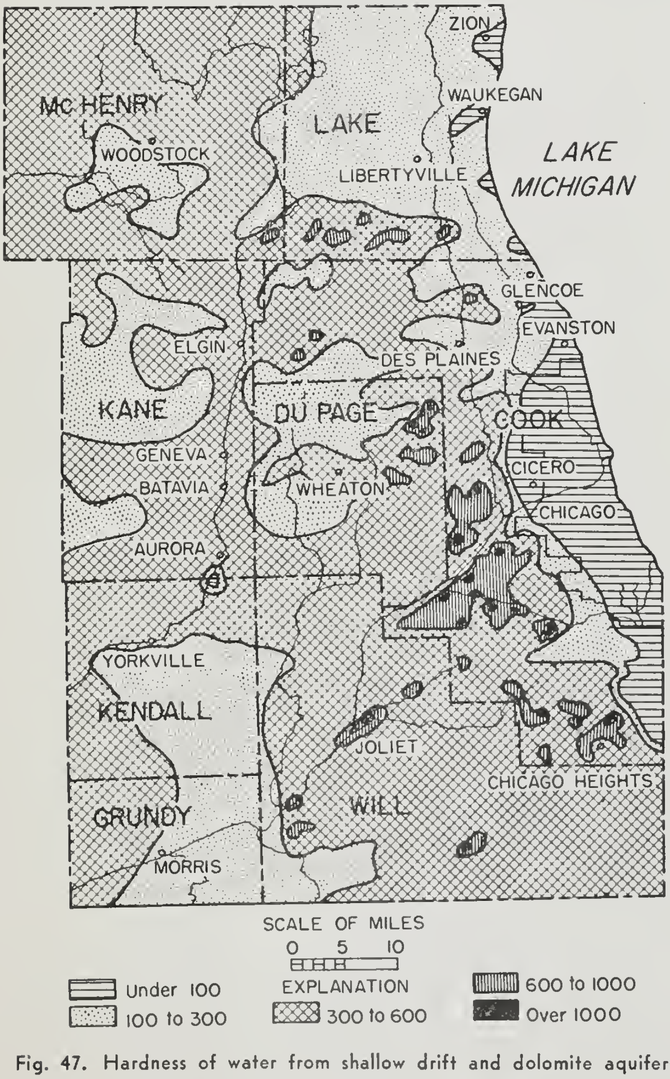


Fig. 47. Hardness of water from shallow drift and dolomite aquifers.

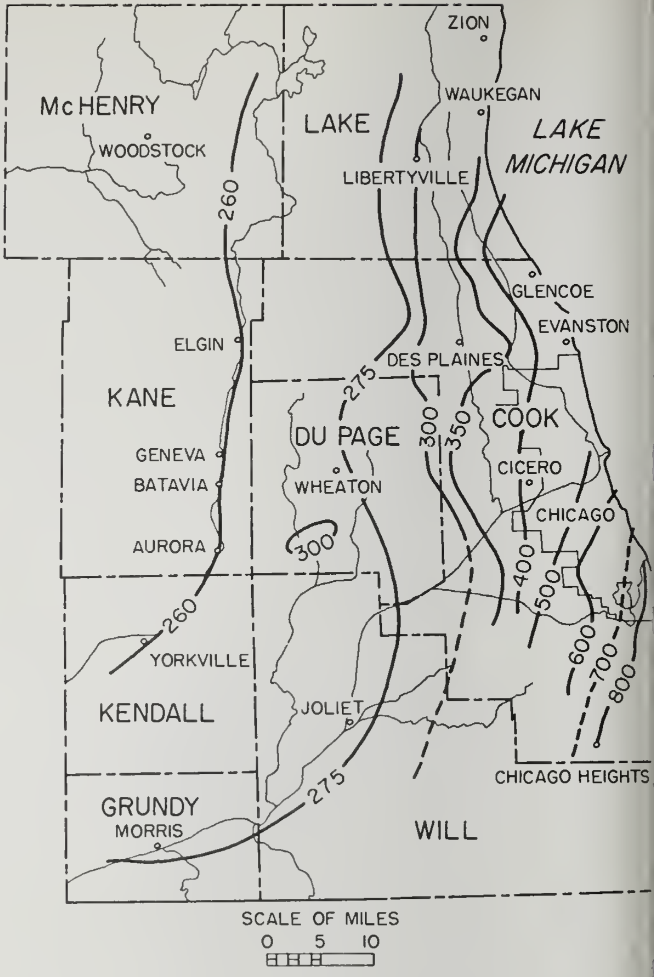
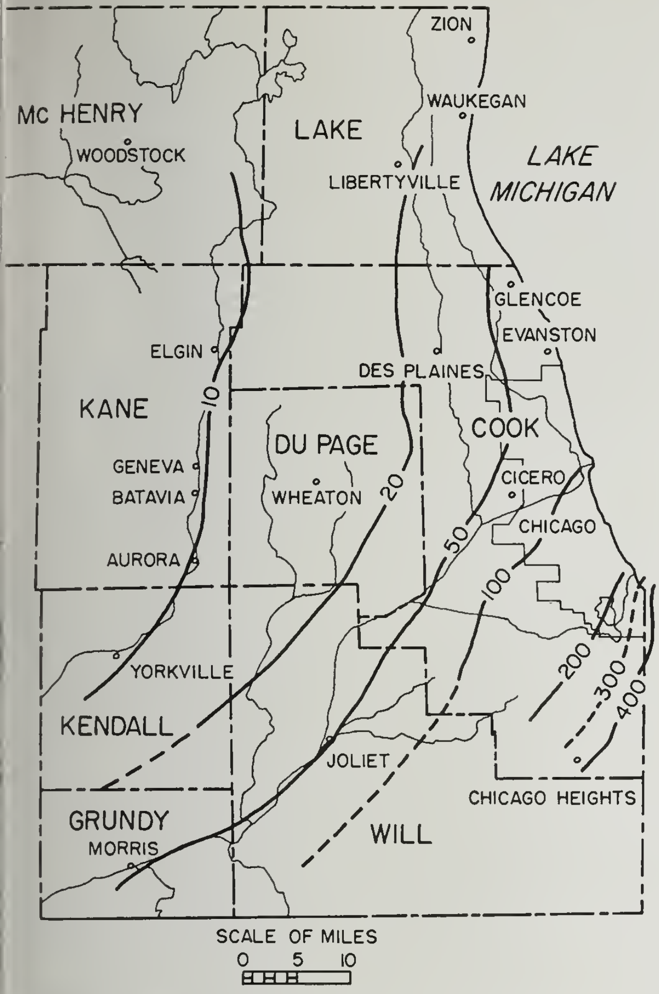


Fig. 48. Hardness of water from Cambrian-Ordovician Aquifer

The quality may also be influenced by small quantiti of water from the Galena-Platteville Dolomite which characterized by high alkalinity (above 350 ppm), lo hardness (less than 100 ppm), absence of sulfates, a usually sufficient hydrogen sulfide to be detected by i odor (Appendix A).

If the deeper wells are not cased through the shallo drift and dolomite aquifers with a pressure-grout annular envelope of cement around the casing, the wat from shallow aquifers, by virtue of its higher hydrostat pressure, will enter the well bore during idle periods well as pumping periods. Although this contributi may be relatively small, the iron content and hardne may be seriously high in the pumped water, particular at the beginning of the pumping period. Such iro bearing water entering the well bore during idle perio will also tend to penetrate permeable formations, positing the iron at or near the face of the bore ho thereby causing loss in well capacity. This effect is se ous because the penetration is selective, being greater the more permeable and productive zones.



. 49. Chloride content of water from Cambrian-Ordovician Aquifer.

When not blended with waters from other formations, ters from the Glenwood-St. Peter and Ironton-Gales-le Sandstones usually have low iron content (0.2– ppm) and an almost uniform concentration of 1.0 m fluoride.

Simon Aquifer

The primary characteristic of the quality of water m the Mt. Simon Aquifer is its rapid increase in oride concentration with depth of penetration or er elevation, as shown in figure 50. With increasing etration below an elevation of 1275 feet below sea el, greater quantities of water with high chloride tent and high hardness are permitted to enter a well. e rate of increase in chloride concentration with in-asing depth in the aquifer approaches 400 ppm per litional 25 feet of penetration. This rate is based gely on data from a sample collected from an oil test ll in Kankakee County at an elevation of 2200 feet ow sea level (Appendix A).

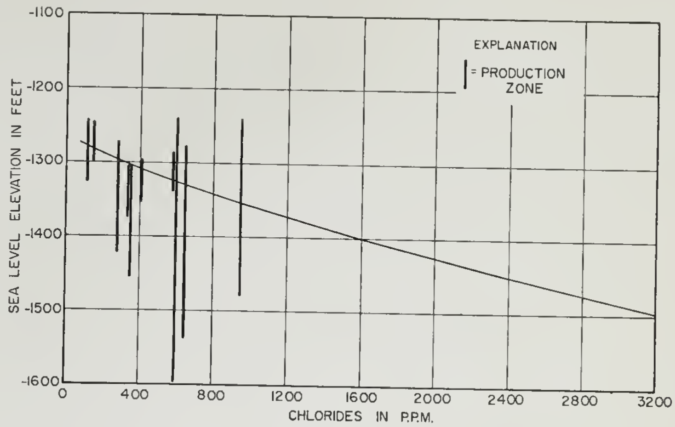


Fig. 50. Elevation versus chlorides in the Mt. Simon Aquifer.

Abandoned wells penetrating Mt. Simon Aquifer in region may contribute high chloride water to the overlying Cambrian-Ordovician Aquifer because the major pumpage and water-level decline is in the latter. Therefore the upper aquifer in the immediate area of such abandoned wells may yield an increasing proportion of Mt. Simon water with continued water-level decline.

RECOMMENDATIONS FOR FURTHER STUDY

The presently available data are insufficient to form a basis for a complete or accurate water resources budget of the Chicago region. More detailed geologic, hydrologic, meteorologic, and engineering data, bearing on both ground water and surface water, are needed. With respect to ground water the following investigations are recommended:

1) Study of the shallow aquifers to delineate favorable and unfavorable areas for additional ground-water development, and to determine recharge, hydraulic properties, and potential yield.
2) Regional study of the stratigraphy of the deeper formations to determine variations in permeability, nature of barrier boundaries, role of the dolomites of the Prairie du Chien and Trempealeau Formations as contributors of water, and the detailed character of the Eau Claire Formation.
3) Study of the effects that dewatering parts of the Cambrian-Ordovician Aquifer has on water-level declines.
4) Study of possible recharge of the aquifers from Lake Michigan.
5) Study of the relations between the Chicago and Milwaukee pumpage cones.
6) Application of more extensive geophysical logging and well testing to obtain additional geologic and hydrologic data on individual units of the aquifers.
7) Collection of more complete data on pumpage, particularly from the shallow aquifers.

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APPENDIX A

SELECTED MINERAL ANALYSES OF WATER

Abbreviations used:

ppm = parts per million

epm = equivalents per million

ppm × .0583 = grains per gallon

GLACIAL DRIFT AQUIFER

ample of water collected from 6-inch well owned by the Morton lt Co. between Woodstock and Crystal Lake, Illinois, in McHenry unty. Location of well: 6 feet from 1200 feet E and 300 feet S NW corner of Section 16, T44N, R7E. Depth of well: 231 feet.

LABORATORY NO. 134325

		ppm	epm
rbidity		14.	
lor		0.	
lor		0.	
on (total)	Fe	2.3	
nganese	Mn	0.0	
lcium	Ca	81.	4.05
gnesium	Mg	47.	3.87
nmonium	NH_4	0.6	0.03
dium	Na	7.	0.31
ica	SiO_2	22.7	
uoride	F	0.2	
ron	B	Tr.	
loride	Cl	8.	.23
trate	NO_3	0.2	Tr.
lfate	SO_4	5.3	.11
kalinity	(as $CaCO_3$)	396.	7.92
rdness	(as $CaCO_3$)	396.	7.92
tal Dissolved Minerals		392.	

SHALLOW DOLOMITE AQUIFER

Sample of water collected October 18, 1945, from Well No. 5 ned by the Village of Palatine, Illinois. Location of well: 2000 t S and 2000 feet W of NE corner of Section 22, T42N, R10E. pth of well: 209 feet. Rate of pumping: 235 gpm for 6 hours.

LABORATORY NO. 104554

		ppm	epm
bidity		30.	
or		0.	
r		0.	
n (total)	Fe	1.4	
ganese	Mn	0.2	
cium	Ca	75.8	3.79
gnesium	Mg	58.5	4.80
monium	NH_4	Tr.	Tr.
ium	Na	62.	3.70
a	SiO_2	18.0	
ride	Cl	4.	.11
rate	NO_3	4.2	.07
ate	SO_4	422.5	8.79
linity	(as $CaCO_3$)	116.	2.32
dness	(as $CaCO_3$)	430.	8.59
l Dissolved Minerals		756.	
p. (reported)		51° F.	
(reported)		7.6	

SHALLOW DOLOMITE AQUIFER

Sample of water collected March 18, 1958, from a well owned by the Midwest-Justice Water Co. near Justice, Illinois, in Cook County. Location of well: 500 feet E and 1430 feet S of NW corner of Section 35, T38N, R12E. Depth of well: 145 feet. Sample collected 5 minutes after pumping began while pumping at a rate of 137 gpm.

LABORATORY NO. 146026

		ppm	epm
Turbidity		16.	
Color		0.	
Odor		0.	
Iron (total)	Fe	2.6	
Manganese	Mn	0.1	
Calcium	Ca	283.0	14.15
Magnesium	Mg	201.6	16.58
Ammonium	NH_4	0.7	.04
Sodium	Na	41.	1.78
Silica	SiO_2	25.3	
Fluoride	F	0.2	
Boron	B	0.3	
Chloride	Cl	10.	.28
Nitrate	NO_3	0.4	.01
Sulfate	SO_4	1079.1	22.50
Alkalinity	(as $CaCO_3$)	488.	9.76
Hardness	(as $CaCO_3$)	1536.	30.73
Total Dissolved Minerals		2025.	
Temp. (reported)		52° F.	

GALENA-PLATTEVILLE DOLOMITE

Sample of water collected October 5, 1936, from a well owned by the Illinois Watch Case Co., Elgin, Illinois. Location of well: Section 12, T41N, R8E. Depth of well: 981 feet.

LABORATORY NO. 78810

		ppm	epm
Turbidity		10.	
Color		0.	
Odor (at well)		H_2S	
Iron (total)	Fe	1.2	
Manganese	Mn	0.0	
Calcium	Ca	17.5	.88
Magnesium	Mg	8.4	.69
Ammonium	NH_4	0.7	.04
Sodium	Na	112.	4.87
Silica	SiO_2	12.	
Chloride	Cl	4.	.11
Nitrate	NO_3	5.3	.09
Sulfate	SO_4	0.0	.00
Alkalinity	(as $CaCO_3$)	314.	6.28
Hardness	(as $CaCO_3$)	79.	1.57
Total Dissolved Minerals		349.	

CAMBRIAN-ORDOVICIAN AQUIFER

Sample of water collected January 13, 1957, from the No. 3 Well owned by the Caterpillar Tractor Company near Montgomery, Illinois, in Kendall County. Location of well: 2500 feet N and 2170 feet E of SW corner of Section 6, T37N, R8E. Depth of well: 1352 feet. Sample collected 24 hours after pumping began while pumping at a rate of approximately 1277 gpm.

LABORATORY NO. 142509

		ppm	epm
Turbidity		0.	
Color		0.	
Odor		0.	
Iron (total)	Fe	0.3	
Manganese	Mn	0.0	
Calcium	Ca	63.7	3.19
Magnesium	Mg	23.0	1.89
Ammonium	NH_4	0.8	0.04
Sodium	Na	32.	1.41
Silica	SiO_2	7.4	
Fluoride	F	0.7	
Boron	B	0.4	
Chloride	Cl	10.	0.28
Nitrate	NO_3	0.3	Tr.
Sulfate	SO_4	39.1	0.81
Alkalinity	(as $CaCO_3$)	272.	5.44
Hardness	(as $CaCO_3$)	254.	5.08
Total Dissolved Minerals		336.	

CAMBRIAN-ORDOVICIAN AQUIFER

Sample of water collected August 21, 1942, from well owned Carnegie Illinois Steel Corp., South Chicago, Illinois. Locati of well: 2500 feet N and 2600 feet E of SW corner of Secti 32, T38N, R15E. Depth of well: 1660 feet.

LABORATORY NO. 93750

		ppm	ep
Turbidity		10.	
Color		0.	
Odor		0.	
Iron (total)	Fe	0.9	
Manganese	Mn	0.0	
Calcium	Ca	198.8	9.
Magnesium	Mg	74.3	6.
Ammonium	NH_4	0.5	0.
Sodium	Na	230.	9.
Silica	SiO_2	11.0	
Chloride	Cl	207.	5.
Nitrate	NO_3	1.1	0.
Sulfate	SO_4	757.8	15.
Alkalinity	(as $CaCO_3$)	222.	4.
Hardness	(as $CaCO_3$)	802.	16.
Total Dissolved Minerals		1626.	

MT. SIMON AQUIFER

Sample of water collected October 8, 1930, by C. McRoberts from a well being drilled one-fourth mile west of Momence, Illinois, Section 24, T31N, R13E. Depth of well: 2800 feet.

LABORATORY NO. 67647

		ppm	epm
Iron (total)	Fe	0.2	
Manganese	Mn	0.4	
Calcium	Ca	1140.	57.00
Magnesium	Mg	296.4	24.36
Ammonium	NH_4	9.0	.50
Sodium	Na	13153.	572.90
Silica	SiO_2	11.0	
Chloride	Cl	22480.	633.94
Nitrate	NO_3	1.8	.03
Sulfate	SO_4	833.5	17.34
Alkalinity	(as $CaCO_3$)	120.	2.40
Hardness	(as $CaCO_3$)	4068.	81.36
Total Dissolved Minerals		38002.	

APPENDIX B

SELECTED WELL RECORDS

Wells listed below are shown in figure 2 and can be identified the location method of numbering described in the right-hand umn. Abbreviations:

COK = Cook
DUP = DuPage
GRY = Grundy
KNE = Kane

KEN = Kendall
LKE = Lake
MCH = McHenry
WIL = Will

P = Public Supply
I = Industrial Supply
R = Rural (non-irrigation) Supply
R = Irrigation Supply
L = Sea Level
)r = Drift
il = Silurian
q = Maquoketa
O = Cambrian-Ordovician
P = Galena-Platteville
P = Glenwood-St. Peter

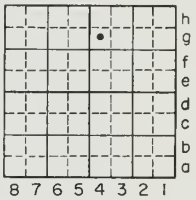
PdC = Prairie du Chien
Tr = Trempealeau
Fr = Franconia
I-G = Ironton-Galesville
EC = Eau Claire
MS = Mt. Simon
S & G = sand and gravel
Dol = dolomite
Ss = sandstone
SS = State Geological Survey sample set
DL = driller's log

WELL NUMBERING SYSTEM

The well numbering system used in the appendix is based on the location of the well, and uses the township, range, and section for identification.

The well number consists of five parts: county abbreviation, township, range, section, and coordinate within the section. Sections are divided into rows of one-eighth mile squares. Each one-eighth mile square contains 10 acres and corresponds to a quarter of a quarter of a quarter section. A normal section of one square mile contains eight rows of eighth-mile squares; an odd-size section contains more or fewer rows. Rows are numbered from east to west and lettered from south to north as shown below.

Cook County
T. 41 N., R. 11 E.,
sec. 25



The number of the well shown in sec. 25 above is as follows:
COK 41N11E-25.4g

Where there is more than one well in a 10-acre square they are identified by arabic numbers after the lower case letter in the well number.

Well No. *(location)*	Owner	Use	Year drilled	Surface elevation above sea level	Depth *(ft.)*	Deepest formation reached	Main aquifer	Type of record
COOK COUNTY								
K 35N13E-1.2c	Flossmoor #1	P	1925	675	467	Sil	Sil Dol	SS 6296; DL
K 35N13E-26.8b	Matteson #2	P	1956	706	305	Sil	Sil Dol	SS 26488; DL
K 35N14E-6.7g	Homewood #3	P	1945	660	435	Maq	Sil Dol	SS 12318; DL
K 35N14E-19.4a	Chicago Hts. #25	P	1958	691	450	Sil	Sil Dol	SS 30746; DL
K 35N14E-21.3h	Calumet Steel #4	I	1951	640	1805	EC	C-O	SS 21216; DL
K 35N14E-21.7e	Chicago Heights #20	P	1942	657	1794	EC	C-O	SS 6283; DL
K 35N14E-21.2h	Chicago Heights #2	P	1918	638	1797	EC	C-O	DL
K 35N14E-28.8h	Chicago Heights	P	1926	690	1832	EC	C-O	SS 534; DL
K 35N14E-29.1c2	South Chicago Heights #2	P	1956	706	250	Sil	Sil Dol	DL
K 35N14E-30.7f	Park Forest #2	P	1948	720	300	Sil	Sil Dol	SS 16187; DL
K 35N15E-29.5h	E J & E RR	I	1929	630	1785	I-G	C-O	SS 1207; DL
K 36N12E-4.1a	Orland Park #2	P	1956	710	397	Sil	Sil Dol	SS 26541; DL
K 36N12E-9.2h	Capital Dairy	I	1943	705	355	Sil	Sil Dol	SS 10209; DL
K 36N13E-1.2c	Miller Potato Co.	I	1958	600	1651	EC	C-O	SS 30712; DL
K 36N13E-16.4h	Oak Forest #2	P	1952	655	295	Sil	Sil Dol	SS 22677
K 36N13E-31.1g3	Tinley Park Hosp. #3	P	1951	697	515	Maq	Sil Dol	SS 20978
K 36N14E-2.8e	Hokin Aluminum Co.	I	1955	590	1730	EC	C-O	SS 25165; DL
K 36N14E-3.1g	Dolton Realty #1	P	1954	589	1704	EC	C-O	DL
K 36N14E-3.6a	Dolton City	P	....	602	1312	Tr	G-SP/Tr	SS 27618; DL
K 36N14E-5.2b	City Ice & Fuel Co.	I	1944-45	600	1657	EC	C-O	SS 12698; DL
K 36N14E-17.4e	Publix Gr. St. Theatres	P	1941	603	470	Maq	Sil Dol	SS 5977; DL
K 36N14E-27.5a	Thornton #3	P	1943	622	250	Sil	Sil Dol	DL
K 36N14E-31.5d	Homewood #2	P	1933	652	1350	Tr	G-SP/Tr	SS 1303; DL
K 36N14E-32.3h	Washington Park	P & IR	....	623	1686	EC	C-O	DL
K 36N14E-34.5g	Frederick's Brewing	I	1944	617	1756	EC	C-O	SS 11473
K 36N14E-34.5d1	Thornton #1	P	1923	617	477	Maq	Sil Dol	DL
K 36N14E-34.5d2	Thornton #2	P	1954	621	1780	EC	C-O	SS 24558
K 36N15E-6.2g	Red River #1	I	1941	585	1625	I-G	C-O	SS 6739; DL
K 36N15E-31.2d	Lansing #1	P	1921	623	1632	I-G	C-O	DL
K 37N11E-29.5f	Lemont City Well	P	1925	735	1235	G-SP	G-SP	DL

Well No. *(location)*	Owner	Use	Year drilled	Surface elevation above sea level	Depth *(ft.)*	Deepest formation reached	Main aquifer	Type of record
			COOK COUNTY—(Continued)					
COK 37N13E-4.5a	Oak Lawn #1	P	1931	611	1946	MS	C-O/MS	DL
COK 37N13E-5.1a	Oak Lawn #2	P	1937	614	1600	EC	C-O	SS 2171; DL
COK 37N13E-19.1b	Jurge Humphries	..	1925	596	1385	Tr	G-SP/Tr	SS 513; DL
COK 37N13E-26.1g	Oak Hill Cemetery #2	I	1958	617	1636	EC	C-O	DL
COK 37N13E-36.2e	Blue Island #3	P	1909-10	640	1650	EC	C-O	DL
COK 37N14E-13.1d	By-Products Coke #1	I	1916	588	1733	EC	C-O	DL
COK 37N14E-17.6g	Washington Hts.	P	1889	618	1308	Tr	G-SP/Tr	DL
COK 37N14E-22.1d	Sherwin-Williams	I	1907	587	1634	EC	C-O	DL
COK 37N15E-5.6h	Illinois Steel #2	I	1930	594	1680	EC	C-O	DL
COK 37N15E-6.4c	John Mohr & Sons	I	1926-27	587	1601	I-G	C-O	SS 868
COK 37N15E-8.3c	A. Schwill Co. #2	I	1944	602	1735	EC	C-O	SS 11008; D
COK 37N15E-18.8h	....	..	1913	592	1706	EC	C-O	DL
COK 38N12E-1.8g	Lyons City Well	P	....	618	2020	MS	C-O/MS	DL
COK 38N12E-4.8d	Public Service Co. #3	P	....	647	1982	EC	C-O	DL
COK 38N12E-4.2d	Public Service Co.#4	P	1928	629	2008	MS	C-O/MS	SS 814; DL
COK 38N12E-5.1h	Nazareth Acad. H.S.	P	1926-27	642	1902	EC	C-O	DL
COK 38N12E-5.3e	La Grange #6	P	1950	680	203	Sil	Sil Dol	SS 20292
COK 38N12E-5.8c	Western Springs #1	P	1924	671	385	Maq	Sil Dol	DL
COK 38N12E-5.8b	Western Springs #2	P	1923	671	385	Maq	Sil Dol	DL
COK 38N12E-6.5a	Western Springs	P	....	646	2046	MS	C-O/MS	DL
COK 38N12E-10.5d	Electro-Motive #1	I	1935	620	1590	EC	C-O	SS 1682
COK 38N12E-10.8d	Electro-Motive #2	I	1937	647	1989	MS	C-O/MS	SS 2402; DL
COK 38N12E-11.3e	Lewis Tar #2	I	1943	607	1172	Tr	G-SP/Tr	SS 10746; D
COK 38N12E-11.7c	Universal Oil Co.	I	1939	607	1564	I-G	C-O	DL
COK 38N12E-18.8g	Cook Co. TB San #3	P & IR	1958	689	1540	EC	C-O	SS 31261; D
COK 38N12E-23.1h	Corn Products #11	I	1942	595	1543	EC	C-O	SS 7501; DL
COK 38N12E-24.8g	Corn Products #12	I	1942	597	1507	EC	C-O	SS 8547; DL
COK 38N12E-24.7f	Corn Products #14	I	1944	612	1481	I-G	C-O	SS 11481; D
COK 38N12E-28.7d	Buick Jet #2	I	1952	600	1535	EC	C-O	SS 22426
COK 38N12E-29.1d	Buick Motor #1	I	1952	605	1515	EC	C-O	SS 22425; D
COK 38N13E-12.8e	International Rolling Mills #1	I	1947	598	1620	I-G	C-O	SS 16353; D
COK 38N13E-19.4g	Visking Corp.	I	1938	617	1515	I-G	C-O	SS 3354; DL
COK 38N13E-21.7f	Continental Can	I	1936	615	1500	I-G	C-O	SS 1754; DL
COK 38N13E-21.1f	Cracker Jack Co.	I	1940	622	1500	I-G	C-O	SS 5131; DL
COK 38N13E-27.5e	Ford #2	I	1956	617	1560	I-G	C-O	SS 27785
COK 38N14E-4.7h	Mullen's Brewery	I	1913	594	1632	I-G	C-O	DL
COK 38N14E-5.3b	Prod. 45th St. Stock Yds.	R	1951	594	1605	EC	C-O	SS 21641
COK 38N14E-6.1f	Wilson Packing Co.	I	1929	593	1700	EC	C-O	SS 823
COK 38N14E-7.7h	Fleischman's Yeast	I	1919	594	1962	EC	C-O	DL
COK 38N14E-7.7c	Fleischman Malting Co.	I	1936	595	1966	EC	C-O	SS 1988; DL
COK 38N14E-8.1g	Nutriment Co.	I	1899	593	1308	Tr	G-SP/Tr	DL
COK 39N12E-4.3h	Indiana H. B. RR. #4	I	1925	634	2007	MS	C-O/MS	DL
COK 39N12E-4.2b	Richardson Co.	I	1940	632	1960	MS	C-O/MS	SS 5130; DL
COK 39N12E-5.5d	C. & N.W. RR. Co. #3	I	1912	644	1830	EC	C-O	SS 62; DL
COK 39N12E-6.5e	C. & N.W. Freight Hse.	I	1926-28	657	1555	EC	C-O	DL
COK 39N12E-9.6f	Bellwood Village #2	P	1929	634	1960	EC	C-O	DL
COK 39N12E-9.2h	Solar-Sturges Mfg.	I	1927	632	1550	EC	C-O	SS 1117; DL
COK 39N12E-9.5a	Bellwood Village	P	1949	631	1951	EC	C-O	DL
COK 39N12E-11.7e	Maywood City #4	P	1918	626	2048	MS	C-O/MS	DL
COK 39N12E-12.1f	Wieboldt's Store	P	1937	631	1620	I-G	C-O	DL
COK 39N12E-12.3e	Bowman Dairy Co.	I	1930	632	2060	MS	C-O/MS	SS 1041; DL
COK 39N12E-13.1e	Borden Dairy Co.	I	1923	620	1615	I-G	C-O	DL
COK 39N12E-14.–	Modern Milk Stores	I	1947	628	372	Sil	Sil Dol	DL
COK 39N12E-15.2g	Maywood City #5	P	1922	628	2076	MS	C-O/MS	DL
COK 39N12E-17.2a	Alum. Co. of America #1	I	1947	630	1495	EC	C-O	SS 16355; D
COK 39N12E-18.1e	Hillside City #1	P	1940	670	1970	MS	C-O/MS	SS 4997; DL
COK 39N12E-18.4b	Mt. Carmel Cemetery	IR	1926	677	1960	MS	C-O/MS	SS 321; DL
COK 39N12E-23.4e	Ed. Hines, Jr. Mem. Hospital	P	1922	623	2010	MS	C-O/MS	SS 232
COK 39N12E-25.5d	Riverside #4	P	1931	621	1980	MS	C-O/MS	DL
COK 39N12E-35.6f	Chicago Zoo. Gardens	P & IR	1927	620	2081	EC	C-O	DL
COK 39N12E-35.3h	Chicago Zoo. Gardens	P & IR	1937	615	2061	MS	C-O/MS	SS 2208; DL
COK 39N12E-36.8d	Riverside #3	P	1924	617	2047	MS	C-O/MS	DL
COK 39N13E-6.1e	Taylor Park	IR	1937	636	990	G-SP	G-SP Ss	SS 3049; DL
COK 39N13E-7.9f	The Fair	P	1937	631	1615	I-G	C-O	SS 2271
COK 39N13E-11.–	Bunte Candy #2	I	1937	603	1940	EC	C-O	SS 2026
COK 39N13E-17.7d	Public Utilities	P	1913	618	1896	EC	C-O	DL
COK 39N13E-21.7h	Kropp Forge	I	1955	610	1635	EC	C-O	SS 26182
COK 39N13E-21.5g	Nat'l. Malleable Casting	I	....	608	1975	MS	C-O/MS	DL
COK 39N13E-24.3h	American Malting	I	1897	593	1303	Tr	G-SP/Tr	DL
COK 39N13E-27.7g	Western Electric #3	I	1941	600	1574	I-G	C-O	DL

Well No. *(location)*	Owner	Use	Year drilled	Surface elevation above sea level	Depth *(ft.)*	Deepest formation reached	Main aquifer	Type of record
	COOK COUNTY—(Continued)							
COK 39N13E-35.1h	Liquid Carbonic Co.	I	1935	597	1558	EC	C-O	SS 1735; DL
COK 39N14E-4.5e	Oscar Mayer	I	1909	592	1626	I-G	C-O	DL
COK 39N14E-4.8h	Crystal Ice	I	1897	592	1614	I-G	C-O	DL
COK 39N14E-5.5h	Chicago Brewery	I	....	591	1875	EC	C-O	DL
COK 39N14E-7.8h	Fleischman's Yeast	I	1919	600	1962	EC	C-O	DL
COK 39N14E-7.2d	Consolidated Bottling	I	1912	600	1625	I-G	C-O	DL
COK 39N14E-16.1f	Chicago Post Office	P	1902	587	1350	Tr	G-SP/Tr	DL
COK 39N14E-16.7g	Fortune Bros. Brewery	I	1912	593	1679	EC	C-O	DL
COK 39N14E-19.5c	Nat'l. Brewing Co.	I	1901	593	1948	EC	C-O	DL
COK 39N14E-19.4d	Nat'l. Beverage Co.	I	1924	593	1948	EC	C-O	DL
COK 39N14E-20.1h	U. S. Brewing Co.	I	1910	592	1609	I-G	C-O	DL
COK 39N14E-21.7b1	Western Shade Cloth #1	I	1940	590	1620	EC	C-O	DL
COK 39N14E-21.7b2	Western Shade Cloth #2	I	1945	590	1603	EC	C-O	SS 14399; DL
COK 39N14E-22.6a	R. R. Donnelly & Sons	I	1935	596	1995	MS	C-O/MS	SS 1681; DL
COK 39N14E-28.2h	Gottfried Brewing Co.	I	1912	593	1658	I-G	C-O	DL
COK 39N14E-28.2d	Inland Rubber Co.	I	1932	605	1936	MS	C-O/MS	DL
COK 40N12E-8.7g	Twin Orchard Country Club	IR	1925	645	1410	Tr	G-SP/Tr	SS 569; DL
COK 40N12E-18.6c	James B. Clow & Sons	R	1956	660	1457	Tr	G-SP/Tr	SS 28042; DL
COK 40N12E-27.8h	Franklin Park #3	P	1931	635	1949	MS	C-O/MS	SS 1114; DL
COK 40N12E-31.2h	North Lake #2	P	1946	648	316	Maq	Sil Dol	DL
OK 40N12E-31.4d	Automatic Electric Co. #1	I	1956	655	1833	EC	C-O	SS 27117; DL
OK 40N12E-31.4c	Automatic Electric Co. #2	I	1956	650	1900	MS	C-O/MS	SS 27118; DL
OK 40N12E-33.6d	Buick Aviation Eng. #1	I	1941	640	1601	EC	C-O	SS 7076; DL
OK 40N13E-15.8a	Sears Roebuck	P	1939	611	1612	EC	C-O	DL
OK 40N13E-31.4g	Shriner's Hospital	P	1930	650	1580	EC	C-O	SS 979; DL
OK 40N13E-31.4e	Mars, Inc. #1	I	1928	650	2033	MS	C-O/MS	DL
OK 40N13E-32.6d	C. M. & St. P. RR.	I	1905	633	1819	EC	C-O	DL
OK 40N13E-34.6d	Hales & Hunter	I	1943	607	1548	EC	C-O	SS 9842; DL
OK 40N14E-17.5d	Graceland Cemetery	IR	1895	599	1568	I-G	C-O	DL
OK 40N14E-20.8c	American Colortype	I	....	598	1580	I-G	C-O	DL
OK 40N14E-30.7c	Durkee Famous Foods	I	1935	590	1945	MS	C-O/MS	SS 1755; DL
OK 40N14E-30.5b	Brand Brewing Co.	I	1915	592	1598	I-G	C-O	DL
OK 40N14E-32.6f	Birk Bros. Brewing	I	1943	597	1600	EC	C-O	SS 10735; DL
OK 40N14E-33.5g	U. S. Brewing (Schmidt)	I	1901	602	1593	I-G	C-O	DL
OK 41N9E-34.1b1	Bartlett #1	P	1923	810	200	Sil	Sil Dol	SS 327; DL
OK 41N9E-34.1b2	Bartlett #2	P	1945	810	200	Sil	Sil Dol	DL
OK 41N10E-15.4f	F & S Industries	I	1955	755	1391	EC	C-O	SS 25944; DL
OK 41N11E-10.3f	Hatlin Heights #2	P	1958	675	1760	EC	C-O	DL
OK 41N11E-12.8h	Mt. Prospect #3	P	1945	670	1348	EC	C-O	SS 12335; DL
OK 41N11E-21.1b	Elk Grove Water & Sewer	P	1958	717	1415	EC	C-O	SS 30233; DL
OK 41N12E-12.8b	Eugenia Subdiv. #1	P	1956	656	1415	I-G	C-O	SS 26400; DL
OK 41N12E-14.–	J. P. Leonard & Co.	I	1939	650	1147	G-SP	G-SP Ss	SS 3554; DL
OK 41N12E-15.5a	Croatian Orphanage	P	1926(?)	635	1763	EC	C-O	SS 553
OK 41N12E-16.8g	Camp Kiwanis	P	1941	633	435	Maq	Sil Dol	SS 6431
OK 41N12E-16.5e	G. R. Fourche	R	1945	630	1000	G-SP	G-SP Ss	SS 12099
OK 41N12E-18.6a	Des Plaines #1	P	....	650	1735	MS	C-O/MS	DL
OK 41N12E-18.7a	Des Plaines #2	P	1946	655	1813	MS	C-O/MS	SS 15889; DL
OK 41N12E-19.5c	Des Plaines #3	P	1953	655	1843	MS	C-O/MS	SS 23436; DL
OK 41N12E-19.5e	Des Plaines #4	P	1955	654	1805	MS	C-O/MS	SS 25852; DL
OK 41N12E-21.8g	Des Plaines	P	1924	630	1600	EC	C-O	SS 178
OK 41N13E-8.6d	Glen View Country Club	IR	....	650	2050	MS	C-O/MS	SS 628
OK 41N13E-20.7f	Morton Grove #1	P	....	627	1462	I-G	C-O	DL
OK 41N13E-20.2d	Poehlman Bros.	R	....	628	1966	MS	C-O/MS	SS 646
OK 41N13E-22.5h	New Evanston Golf Club	IR	....	608	1463	Tr	G-SP/Tr	DL
OK 41N13E-23.2b	Petrol Agar	I	1931	597	1680	EC	C-O	SS 1149
OK 41N13E-26.2h	Northwest. Gas, Light & Coke Co.	P	1912	597	1871	MS	C-O/MS	DL
OK 41N13E-29.8d	Lex-Paul Corp. #1	I	1957	624	1465	EC	C-O	SS 27888
OK 42N9E-1.7h	Barrington #2	P	1929	815	310	Sil	Sil Dol	SS 950; DL
OK 42N9E-2.7e	Alex Reichman	R	1929	845	880	G-SP	G-SP Ss	SS 937
OK 42N10E-14.2b	Palatine	P	1954	733	1380	EC	C-O	SS 24960
OK 42N10E-22.4c	Palatine #5	P	1945	740	209	Maq	Sil Dol	SS 13508; DL
OK 42N10E-24.8a	Arlington Park Jockey Club	IR	....	724	920	G-SP	G-SP Ss	SS 959
OK 42N10E-25.7e	Rolling Meadows #1	P	1953	711	1535	EC	C-O	SS 25025; DL
OK 42N10E-25.1h	Rolling Meadows #2	P	1954	710	1401	EC	C-O	SS 24400; DL
OK 42N11E-5.1g	Buffalo Utility #1	P	1957	688	1342	I-G	C-O	DL
OK 42N11E-11.8b	Ekco Foil #2	I	1955	645	1320	EC	C-O	DL
OK 42N11E-11.7e	Wheeling	P	1956	644	1370	EC	C-O	DL
OK 42N11E-29.5a	Arlington Hts. #5	P	1946	689	1525	EC	C-O	SS 14483; DL
OK 42N11E-30.3c	Arlington Hts. #2	P	....	725	1345	EC	C-O	SS 1504
OK 42N11E-30.5b	Arlington Hts. #6	P	1952	705	1475	EC	C-O	SS 16990; DL SS 22691

Well No. *(location)*	Owner	Use	Year drilled	Surface elevation above sea level	Depth *(ft.)*	Deepest formation reached	Main aquifer	Type of record
COOK COUNTY—(Continued)								
COK 42N11E-33.3c	Mt. Prospect #4	P	1949	689	1375	EC	C-O	SS 19845
COK 42N11E-34.8f	Mt. Prospect # 5	P	1954	676	1820	MS	C-O/MS	SS 25168
COK 42N11E-36.4b	St. Mary's Academy	P	1923-26	643	1535	MS	C-O/MS	SS 506
COK 42N12E-5.7d	Marshall Salzman	R	1957	687	1404	G-SP	G-SP Ss	SS 28043; D
COK 42N12E-9.3c	Northbrook City	P	....	646	1345	EC	C-O	SS 49; DL
COK 42N12E-14.7f	St. Mary's #2	P & IR	1931	666	1983	MS	C-O/MS	SS 1118; DL
COK 42N12E-29.1a	Ill. Municipal #4	P	1957	677	1405	I-G	C-O	SS 27885; D
COK 42N12E-29.6b	E. S. Beck	R	....	684	1935	MS	C-O/MS	SS 1039; DL
COK 42N12E-33.4b	Glenview C'tryside #1	P	1940	681	570	G-P	G-P Dol	SS 5199; DL
COK 42N12E-33.7b	Glenview C'tryside #2	P	1941	680	606	G-P	G-P Dol	SS 6596; DL
COK 42N12E-33.1c	Glenview #3	P	1954	671	917	G-P	Sil Dol	SS 24480; D
COK 42N12E-34.4d	Glenview #2	P	....	652	1431	EC	C-O	SS 540
COK 42N12E-35.4d	Baxter Lab.	I	1939	628	1050	Tr	G-SP/Tr	SS 3740; DL
COK 42N12E-36.8e	North Shore C.C. #1	IR	1923	647	1330	I-G	C-O	SS 322
DU PAGE COUNTY								
DUP 37N11E-3.8a	Argonne Nat'l. Lab.	I	1950	676	1595	EC	C-O	DL
DUP 38N9E-5.5a	Public Ser. Co. No. Ill.	P	1928	730	1333	I-G	C-O	SS 774; DL
DUP 38N9E-13.2b1	Naperville	P	....	673	1425	I-G	C-O	DL
DUP 38N9E-13.2b2	Naperville #3	P	1922	675	130	Sil	Sil Dol	SS 357
DUP 38N9E-17.8d	C. B. & Q. RR.	I	1919	714	1428	I-G	C-O	DL
DUP 38N10E-18.3d1	Naperville #5	P	1930	695	205	Sil	Sil Dol	SS 1140; DL
DUP 38N10E-18.3d2	Naperville #6	P	1937	698	202	Maq	Sil Dol	SS 2173; DL
DUP 38N11E-1.3a	Hinsdale #2	P	1924	686	268	Sil	Sil Dol	SS 766
DUP 38N11E-1.6a	Hinsdale #3	P	1928	687	210	Sil	Sil Dol	DL
DUP 38N11E-4.4f	Liberty Park #2	P	1956	745	275	Maq	Sil Dol	SS 26960; D
DUP 38N11E-7.6d	Downers Grove	P	1927	699	250	Maq	Sil Dol	SS 687; DL
DUP 38N11E-7.1e	Downers Grove	P	1906-07	716	2021	MS	C-O/MS	DL
DUP 38N11E-8.4b	Downers Grove	P	1930	742	295	Sil	Sil Dol	SS 1046; DL
DUP 38N11E-8.7e	Downers Grove	P	1951	715	268	Maq.	Sil Dol	SS 20945
DUP 38N11E-9.1h	Westmont #2	P	1926	752	313	Maq	Sil Dol	SS 560; DL
DUP 38N11E-10.7a	Westmont #3	P	1935	760	302	Sil	Sil Dol	SS 1687; DL
DUP 38N11E-10.8e	Westmont #4	P	1958	755	313	Maq	Sil Dol	SS 30748; D
DUP 38N11E-10.2f	Clarendon Hills	P	1923	730	970	G-SP	G-SP Ss	DL
DUP 38N11E-10.1e	Clarendon Hills #2	P	1932	730	250	Sil	Sil Dol	SS 1231
DUP 38N11E-11.5a	Clarendon Hills #3	P	1945	730	354	Sil	Sil Dol	SS 12835; D
DUP 39N9E-4.1b	West Chicago #3	P	1950	768	310	Maq	Sil Dol	DL
DUP 39N9E-10.7f	Chicago & NW. RR.	I	....	760	2082	MS	C-O/MS	SS 401
DUP 39N9E-13.6h	Winfield #1	P	1926	720	200	Sil	Sil Dol	DL
DUP 39N9E-13.6b	Winfield #2	P	1957	778	335	Maq	Sil Dol	SS 27666; D
DUP 39N10E-9.2f	Wheaton #5	P	1954	752	341	Maq	Sil Dol	SS 24881; D
DUP 39N10E-11.7c	Glen Ellyn #2	P	1922	761	352	Maq	Sil Dol	SS 1048
DUP 39N10E-11.8d	Glen Ellyn #3	P	1941	789	422	Maq	Sil Dol	SS 6215; DL
DUP 39N10E-16.6c1	Wheaton #3	P	1930	739	184	Maq	Sil Dol	SS 961; DL
DUP 39N10E-16.6c2	Wheaton #4	P	1946	745	350	Maq	Sil Dol	SS 15659
DUP 39N11E-1.8g	Elmhurst #1	P	1915	684	1480	EC	C-O	SS 4229; DL
DUP 39N11E-2.2f	Elmhurst #3-A	P	1942-43	690	1502	EC	C-O	SS 10228; D
DUP 39N11E-4.1f	Villa Park #6	P	1958	704	1420	EC	C-O	DL
DUP 39N11E-6.5a	Lombard #4	P	1953	700	2062	MS	C-O/MS	SS 23911; D
DUP 39N11E-8.7h	Lombard #2	P	1926	703	2038	MS	C-O/MS	DL
DUP 39N11E-9.1h	Villa Park #1	P	....	695	2125	MS	C-O/MS	DL
DUP 39N11E-10.8e	Villa Park #4	P	1923	702	223	Maq	Sil Dol	SS 128
DUP 39N11E-10.4g	Wander Co. #1	I	1927	677	1970	MS	C-O/MS	DL
DUP 39N11E-10.1h	Elmhurst #4	P	1928	665	2205	MS	C-O/MS	DL
DUP 39N11E-10.3g	Wander Co. #11	I	1946	675	1920	MS	C-O/MS	SS 15336
DUP 39N11E-12.8d	Elmhurst #5	P	1940	675	1480	I-G	C-O	DL
DUP 40N9E-29.6a	Howard Aircraft Corp.	I	1942	755	1006	G-SP	G-SP Ss	SS 9843; DL
DUP 40N9E-32.2d	Elgin, Joliet & Eastern RR.	I	1931	755	1378	EC	C-O	SS 1169; DL
DUP 40N9E-36.6h	Mark Morton #1	R	1930	802	912	G-SP	G-SP Ss	SS 1045; DL
DUP 40N10E-14.4c	Glendale Country Club	IR	....	757	853	G-SP	G-SP Ss	SS 436
DUP 40N10E-15.2f	Suncrest Highlands	P	1956	722	1395	EC	C-O	SS 27477
DUP 40N11E-11.5a	Mohawk Country Club	IR	1935	677	1456	EC	C-O	DL
DUP 40N11E-13.8e.	Bensenville #2	P	1929	672	1442	EC	C-O	SS 956; DL
DUP 40N11E-13.3c	C. M. & St. P. RR. #1	I	1912	665	2290	MS	C-O/MS	DL
DUP 40N11E-13.5b	C. M. & St. P. RR. #6	I	1950	672	1461	EC	C-O	SS 20203; D
DUP 40N11E-14.1d	Bensenville #3	P	1956	677	1445	EC	C-O	SS 25024
DUP 40N11E-28.3f	Addison	P	1924	690	155	Sil	Sil Dol	DL
DUP 40N11E-35.5e	Elmhurst #6	P	1954	700	1476	EC	C-O	SS 24957
GRUNDY COUNTY								
GRY 33N6E-3.3a	M. B. Wilson	R	....	570	353	G-SP	G-SP Ss	DL
GRY 33N6E-3.1a	M. B. Wilson	R	1941	570	330	G-SP	G-SP Ss	DL

Well No. *(location)*	Owner	Use	Year drilled	Surface elevation above sea level	Depth *(ft.)*	Deepest formation reached	Main aquifer	Type of record
GRUNDY COUNTY—(Continued)								
RY 33N6E-4.2h	Andrew Johnson	R	....	605	330	G-SP	G-SP Ss	DL
RY 33N6E-8.4h	....	..	....	580	388	G-SP	....	DL
RY 33N6E-8.2d	Sam Holderman	R	1918	605	338	G-SP	G-SP Ss	DL
RY 33N6E-9.2d	Sam Holderman	R	....	535	290	G-SP	G-SP Ss	DL
RY 33N6E-10.6f	S. J. Holderman	R	1950	530	300	G-SP	G-SP Ss	DL
RY 33N6E-11.4f	Morris Clay Products	I	1955	530	406	G-SP	G-SP Ss	DL
RY 33N6E-12.6e	Graver Packing Co.	I	1951	518	372	G-SP	G-SP Ss	DL
RY 33N6E-15.6f	....	..	....	500	291	G-SP	....	DL
RY 33N6E-21.7h	Alice Wahe	R	....	500	285	G-SP	G-SP Ss	DL
RY 33N6E-22.4d	W. H. Croft	R	....	595	374	G-SP	G-SP Ss	DL
RY 33N6E-27.2d	Dr. A. G. Harrison	R	....	608	494	G-SP	G-SP Ss	DL
RY 33N6E-29.4e	Du Pont #6	I	1955	610	1530	EC	C-O	SS 25493
RY 33N6E-30.6g	Prairie States	I	1950	495	310	G-SP	G-SP Ss	DL
RY 33N7E-4.4c	Morris #5	P	1954	505	1462	EC	C-O	SS 24398
RY 33N7E-4.2a	Cater Contracting #3	I	1915	523	720	G-SP	G-SP Ss	SS 47
RY 33N7E-5.5h	F. W. Anderson	R	1949	550	480	G-SP	G-SP Ss	DL
RY 33N7E-6.6h	Morris Country Club	IR	1926	548	385	G-SP	G-SP Ss	DL
RY 33N7E-9.3h	Morris #4	P	1938	510	1501	EC	C-O	DL
RY 33N7E-12.4a	F. J. Holderman	R	1915	525	608	G-SP	G-SP Ss	DL
RY 33N7E-13.1d	F. J. Holderman	R	1904	543	623	G-SP	G-SP Ss	DL
RY 33N7E-19.8g	Lory Dempsey	R	....	580	449	G-SP	G-SP Ss	DL
RY 33N7E-20.8g	Peter Dittmyer	R	1939	518	428	G-SP	G-SP Ss	DL
RY 33N7E-26.6e	Frank Young	R	1914	550	535	G-SP	G-SP Ss	DL
RY 33N7E-33.5a	Grundy Co. Poor Farm #1	P	1929	570	730	PdC	G-SP Ss	SS 698; DL
RY 33N8E-11.5g	Ill. Clay Products Co.	I	....	510	500	G-SP	G-SP Ss	SS 329
RY 33N8E-18.4c	Jno. Holderman	R	....	540	660	PdC	G-SP Ss	DL
RY 33N8E-34.6g	Carbon Hill	P	1942	560	650	G-SP	G-SP Ss	SS 8899; DL
RY 33N8E-34.5a	E. J. & E. RR.	I	1910	565	1346	EC	C-O	DL
RY 34N6E-3.1a	O. J. Larson	R	1901	610	200	G-SP	G-SP Ss	DL
RY 34N6E-5.1g	P. David	R	1916	668	202	G-SP	G-SP Ss	DL
RY 34N6E-5.6a	Andrew Holland	R	1913	665	186	G-SP	G-SP Ss	DL
RY 34N6E-8.4a	O. Dix (O. J. Frey)	R	....	650	301	G-SP	G-SP Ss	DL
RY 34N6E-8.d	Hi. Wicks	R	1916	649	192	G-SP	G-SP Ss	DL
RY 34N6E-9.1h	Frank H. Hayes	R	1942	628	220	G-SP	G-SP Ss	SS 8477; DL
RY 34N6E-13.8h	O. Gunderson	R	....	590	249	G-SP	G-SP Ss	DL
RY 34N6E-14.7h	John Cunnea	R	1902	605	218	G-SP	G-SP Ss	DL
RY 34N6E-15.8h	John Cunnea	R	....	604	229	G-SP	G-SP Ss	DL
RY 34N6E-17.8f	Sidney Jorstad	R	1949	645	295	G-SP	G-SP Ss	DL
RY 34N6E-17.8d	Barton Johnson	R	....	643	295	G-SP	G-SP Ss	DL
RY 34N6E-18.8c	Herbert Wildey	R	....	665	266	G-SP	G-SP Ss	DL
RY 34N6E-18.1e	Ami Morcusson	R	....	650	321	G-SP	G-SP Ss	DL
RY 34N6E-19.3h	Crist Hendrickson	R	....	646	285	G-SP	G-SP Ss	DL
RY 34N6E-19.1b	Wm. E. Jelm	R	....	627	282	G-SP	G-SP Ss	DL
Y 34N6E-19.7g	Arthur C. Wildey	R	....	660	353	G-SP	G-SP Ss	DL
Y 34N6E-20.4e	B. C. Nicholson	R	1955	620	240	G-SP	G-SP Ss	DL
Y 34N6E-20.8a	Nettie Gray	R	1913	625	250	G-SP	G-SP Ss	DL
Y 34N6E-23.2a	....	..	....	585	278	G-SP	....	DL
Y 34N6E-23.1e	....	..	....	585	325	G-SP	....	DL
Y 34N6E-25.7g	Abe Hoge	R	1875	590	1865	MS	C-O/MS	DL
Y 34N6E-26.8d	Hoge School	P	1941	595	320	G-SP	G-SP Ss	SS 7149; DL
Y 34N6E-26.8c	W. M. Hoge	R	....	595	370	G-SP	G-SP Ss	DL
Y 34N6E-28.2b	G. D. Hoge	R	....	605	250	G-SP	G-SP Ss	DL
Y 34N6E-30.8e	Mrs. Brewe	R	....	642	303	G-SP	G-SP Ss	DL
Y 34N6E-31.1h	Lava Olsen	R	1941	630	333	G-SP	G-SP Ss	DL
Y 34N6E-36.8a	F. W. Gebhard	R	1937	560	343	G-SP	G-SP Ss	DL
Y 34N7E-18.5h	Munson Heirs	R	1939	585	285	G-SP	G-SP Ss	SS 3650; DL
Y 34N7E-19.4h	....	..	....	570	303	G-SP	....	DL
Y 34N7E-20.8h	D. Neushwander	R	1952	576	302	G-SP	G-SP Ss	DL
Y 34N7E-30.4a	....	..	....	550	334	G-SP	....	DL
Y 34N7E-31.5a	Tenes Olson	R	1939	540	360	G-SP	G-SP Ss	SS 3953; DL
Y 34N7E-32.1h	....	..	....	545	357	G-SP	....	DL
Y 34N7E-33.1a	Chas. Muffler	R	1949	520	355	G-SP	G-SP Ss	DL
Y 34N7E-34.8d	State of Illinois	R	1955	525	400	G-SP	G-SP Ss	SS 25673; DL
Y 34N7E-35.8e	....	..	....	525	408	G-SP	....	DL
Y 34N8E-35.1g	Dresden Nuclear #1	I	1957	514	788	PdC	G-SP Ss	SS 30332; DL
Y 34N8E-35.1e	Dresden Nuclear #2	I	1957	530	1500	I-G	C-O	SS 29050; DL
KANE COUNTY								
E 38N8E-3.8g	North Aurora #1	P	1938	695	807	G-SP	G-SP Ss	SS 2761; DL
E 38N8E-10.9d	Kane Co. Springbrook San. #2	P	1932	670	772	G-SP	G-SP Ss	SS 1197
E 38N8E-13.8a	Western Wheeled Scraper #2	I	1917	695	1461	EC	C-O	DL

Well No. (location)	Owner	Use	Year drilled	Surface elevation above sea level	Depth (ft.)	Deepest formation reached	Main aquifer	Type of record
KANE COUNTY—(Continued)								
KNE 38N8E-15.3h	Aurora #12A	P	1935	670	2251	MS	C-O/MS	SS 1690; D
KNE 38N8E-15.5h	Aurora #4	P	1895	635	2445	MS	C-O/MS	DL
KNE 38N8E-21.5g	Aurora #10	P	1924	682	2299	MS	C-O/MS	DL
KNE 38N8E-22.6h	American Well Works	I	....	675	701	G-SP	G-SP Ss	DL
KNE 38N8E-22.7d	Tivoli Theatre	P	1940	652	1410	EC	C-O	SS 5080; D
KNE 38N8E-22.8d	Walker Laundry	I	1931	650	1438	I-G	C-O	SS 1134; D
KNE 38N8E-23.1h	Aurora #15	P	1950	694	2150	MS	C-O/MS	SS 20577; D
KNE 38N8E-28.4e	Aurora #7	P	1914-15	630	2163	MS	C-O/MS	SS; DL
KNE 38N8E-32.2d	C. B. & Q. RR. #2	I	1947	640	740	G-SP	G-SP Ss	SS 17443
KNE 38N8E-32.2e	Lyon Metal	I	....	635	659	G-SP	G-SP Ss	DL
KNE 38N8E-32.3c	Montgomery	P	1928	642	175	Maq	Sil Dol	SS 653; DL
KNE 38N8E-32.3d	Montgomery #2	P	1949	640	735	G-SP	G-SP Ss	DL
KNE 38N8E-32.4f	Montgomery #4	P	1958	642	1353	I-G	C-O	SS 30751; D
KNE 38N8E-33.8c	Montgomery #3	P	1957	633	1336	I-G	C-O	SS 30477; D
KNE 38N8E-34.7g	Aurora #16	P	1952	655	1460	EC	C-O	SS 22141; D
KNE 38N8E-35.5h	Aurora City Park	P	1909	700	2460	MS	C-O/MS	DL
KNE 39N6E-3.4a	Kaneland School	P	1956	838	930	G-SP	G-SP Ss	SS 26864
KNE 39N7E-2.6c	Scott Bros. #2	R	1930	815	655	G-SP	G-SP Ss	SS 1042
KNE 39N7E-5.8f	Elburn	P	1899	850	1375	I-G	C-O	DL
KNE 39N7E-6.2g	Elburn Packing #4	I	1954	845	1345	I-G	C-O	SS 23989
KNE 39N7E-9.4d	B. L. Palmer	R	1933	805	670	G-SP	G-SP Ss	DL
KNE 39N7E-24.1e	Sumpter #1	P	1950	720	596	G-SP	G-SP Ss	DL
KNE 39N8E-3.5e	Burgess Norton	I	1950	740	1340	I-G	C-O	SS 21805; D
KNE 39N8E-3.8g	Geneva #3	P	1929	758	2300	MS	C-O/MS	SS 970; DL
KNE 39N8E-3.2b	Geneva #4	P	1944	719	2267	MS	C-O/MS	SS 10863; D
KNE 39N8E-15.6f	Campana #1	I	1936	712	275	G-P	Sil Dol	SS 1919; D
KNE 39N8E-22.3e	Batavia #3	P	1941	667	2200	MS	C-O/MS	SS 6901; D
KNE 40N6E-1.4e	Hyman Freed #1	R	1948	920	747	G-SP	G-SP Ss	DL
KNE 40N6E-26.2e	J. & E. Winterhalter	R	1936	872	641	G-SP	G-SP Ss	DL
KNE 40N7E-12.4g	J. B. Ward	R	1940	855	965	G-SP	G-SP Ss	SS 5637; D
KNE 40N7E-20.1g	Clifton Bowgren #1	R	1950	910	729	G-SP	G-SP Ss	DL
KNE 40N7E-23.4g	School Dist. 303 #2	P	1951	825	670	G-SP	G-SP Ss	DL
KNE 40N8E-21.5f	Crane Estate #1	R	....	740	695	G-SP	G-SP Ss	DL
KNE 40N8E-24.3c	G. C. Moseley #1	R	1945	800	765	G-SP	G-SP Ss	SS 14518;
KNE 40N8E-27.6a	St. Charles #3	P	1919	690	2200	MS	C-O/MS	DL
KNE 40N8E-27.7g	Potowattomie Park	P	1937	690	851	G-SP	G-SP Ss	SS 2411
KNE 40N8E-28.1c	Paramount Distillery	I	1937	725	897	G-SP	G-SP Ss	SS 2113
KNE 40N8E-31.6f	St. Charles Training Sch. #1	P	1955	765	1322	EC	C-O	SS 25474
KNE 40N8E-34.6f	St. Charles #6	P	1956	750	2240	MS	C-O/MS	SS 25360
KNE 40N8E-35.8c	Christ Strown #1	R	1936	700	670	G-SP	G-SP Ss	DL
KNE 41N6E-3.1g	Burlington	P	1941	920	111	Dr	S & G	DL
KNE 41N8E-11.2g	Elgin #5	P	1950	725	1225	EC	C-O	SS 20946
KNE 41N8E-12.3f	Modern Dairy	I	1937	790	800	G-SP	G-SP Ss	SS 2166; D
KNE 41N8E-14.8b	Elgin (Schuyler St.) #5	P	1931	823	1940	MS	C-O/MS	SS 1098
KNE 41N8E-14.2e	Pearsall Butter #1	I	1936	730	655	G-SP	G-SP Ss	SS 2081; D
KNE 41N8E-23.3c	Ill. State Hospital	P	1931-32	738	2000	MS	C-O/MS	SS 1153; D
KNE 41N8E-23.6b	Elgin State Hospital #2	P	1947	772	2000	MS	C-O/MS	SS 21248;
KNE 41N8E-24.1a	Elgin (La Voie Ave)	P	1931	733	1978	MS	C-O/MS	SS 1150
KNE 41N8E-24.3b	Elgin #6	P	1954	760	1255	EC	C-O	SS 24582
KNE 41N8E-27.5e	Elgin State Hosp. Farm	R	1935	810	800	G-SP	G-SP Ss	SS 1737
KNE 41N8E-35.8g	South Elgin #1	P	1929, '38	760	1250	I-G	C-O	SS 773 & 26
KNE 42N6E-21.1a	Hampshire	P	1923	900	1180	I-G	C-O	DL
KNE 42N8E-17.5c	Felix Estate	R	1937	910	952	G-SP	G-SP Ss	SS 2354; D
KNE 42N8E-22.4g	Carpentersville	P	1940	728	1140	I-G	C-O	SS 5731; D
KNE 42N8E-23.7a	Haeger Pottery	I	1940	730	734	G-SP	G-SP Ss	DL
KNE 42N8E-27.5e	West Dundee	P	1957	760	1240	EC	C-O	DL
KENDALL COUNTY								
KEN 35N6E-1.7e	Thomas Weeks #2	R	1953	718	275	G-SP	G-SP Ss	DL
KEN 35N6E-5.b	Nils Nilson	R	1941	670	225	G-SP	G-SP Ss	DL
KEN 35N6E-7.8b	L. P. Dauber	R	1943	632	98	G-SP	G-SP Ss	SS 9580
KEN 35N6E-16.7h	Henry Fatland	R	1953	770	225	G-SP	G-SP Ss	DL
KEN 35N6E-24.1b	....	..	....	670	135	G-SP	....	DL
KEN 35N6E-25.1h	Dr. W. B. Huey	R	1940	670	202	G-SP	G-SP Ss	SS 4845
KEN 35N6E-27.5f	....	..	....	725	233	G-SP	....	DL
KEN 35N6E-29.5c	Virginia Nitterhouse	R	1948	710	235	G-SP	G-SP Ss	DL
KEN 35N6E-31.2e	Paul DeLucia	R	1948	710	317	G-SP	G-SP Ss	DL
KEN 35N6E-32.7h	Paul DeLucia	R	1950	655	920	Tr	G-SP/Tr	SS 20192
KEN 35N6E-32.8h	Paul DeLucia	R	1948	670	225	G-SP	G-SP Ss	DL
KEN 35N7E-30.9g	Elmer Torkelson	R	1940	665	150	G-SP	G-SP Ss	SS 4957
KEN 36N6E-4.4d	Camp Milhurst (YWCA)	P	1926	575	425	G-SP	G-SP Ss	DL

Well No. *(location)*	Owner	Use	Year drilled	Surface elevation above sea level	Depth *(ft.)*	Deepest formation reached	Main aquifer	Type of record
KENDALL COUNTY—(Continued)								
KEN 36N6E-16.5e	Milbrook School	P	1940	630	140	G-SP	G-SP Ss	DL
KEN 36N6E-16.8a	Pees Bros.	R	1941	635	145	G-SP	G-SP Ss	DL
KEN 36N6E-17.–	E. A. Pionke #1	R	1953	615	109	G-SP	G-SP Ss	DL
KEN 36N6E-25.8b	C. R. Johnson	R	1946	720	265	G-SP	G-SP Ss	DL
KEN 36N6E-30.6f	G. L. Harris	R	1947	565	67	G-SP	G-SP Ss	SS 17754
KEN 36N6E-32.4e	Nelson #1	R	1954	775	425	G-SP	G-SP Ss	DL
KEN 36N6E-33.8d	Harry Hughes	R	1947	712	201	G-SP	G-SP Ss	SS 17751; DL
KEN 36N8E-29.8d	Christian	R	1924	620	500	G-SP	G-SP Ss	DL
KEN 36N8E-30.4f	Hill	R	1924	615	500	G-SP	G-SP Ss	DL
KEN 36N8E-36.1d	Rose Procter #1	R	1943-44	647	2325	MS	....	SS 10744; DL
KEN 37N6E-4.4d	Chicago YWCA	P	....	695	425	G-SP	G-SP Ss	DL
KEN 37N6E-7.3g	Clarence Smith	R	....	710	302	G-SP	G-SP Ss	DL
KEN 37N6E-32.5e	W. L. Scantlin	R	1941	640	160	G-SP	G-SP Ss	SS 7623; DL
KEN 37N6E-33.1a	Burr Oak	R	1937	639	550	G-SP	G-SP Ss	DL
KEN 37N7E-22.8g	T. A. Gantt #1	R	1939	628	575	G-SP	G-SP Ss	DL
KEN37N7E-28.4e	John Demetralis	R	1941	640	620	G-SP	G-SP Ss	SS 7977
KEN 37N7E-32.1e	Yorkville	P	1923	584	590	G-SP	G-SP Ss	DL
KEN 37N8E-6.2d	Caterpillar #3	I	1957	661	1352	I-G	C-O	SS 27403; DL
KEN 37N8E-17.6b	Oswego #2	P	1932	656	720	G-SP	G-SP Ss	SS 1219; DL
KEN 37N8E-17.4f	Oswego #3	P	1957	642	1380	EC	C-O	DL
LAKE COUNTY								
KE 43N10E-20.2e	Lake Zurich #3	P	1949	885	443	Maq	Sil Dol	SS 19018; DL
KE 43N11E-2.8g	Covington, W. S. #1	R	1942	677	966	G-SP	G-SP Ss	DL
KE 43N11E-2.8e	Von Beck, Baroness M #1	R	1940	675	919	G-SP	G-SP Ss	SS 5198; DL
KE 43N11E-2.5e	Morse	R	1951	690	965	G-SP	G-SP Ss	SS 21395; DL
KE 43N11E-3.1d	Voevodsky, George	R	1941	680	955	G-SP	G-SP Ss	SS 7044; DL
KE 43N11E-28.2g	Geo. Willand Greenhouse	IR	1927	680	835	G-SP	G-SP Ss	DL
KE 43N12E-7.8e	A.D . Lasker #2	R	1930	695	2000	MS	....	SS 955; DL
KE 43N12E-15.2h	Chi., Milwk., Elect. RR.	I	1904	691	1753	EC	C-O	DL
KE 43N12E-23.5b	Highland Park City	P	1886-87	690	1590	EC	C-O	SS 1317; DL
KE 43N12E-25.4d	E. V. Price	R	....	657	1514	EC	C-O	DL
KE 43N12E-27.5e	C. & NW. RR.	I	....	650	1760	EC	C-O	DL
KE 43N12E-31.8f	Vernon Ridge C. Club	IR	1925	672	1443	I-G	C-O	DL
KE 44N9E-26.1c	Wauconda #3	P	1939	800	257	Sil	Sil Dol	SS 3271; DL
KE 44N11E-1.4f	Thos. E. Wilson	R	....	710	1055	G-SP	G-SP Ss	DL
KE 44N11E-4.2e	K. K. Budd Home	P	1925-26	680	1274	EC	C-O	SS 611; DL
KE 44N11E-4.8g	Chancellor, Gustine, Jr.	R	1950	682	976	G-SP	G-SP Ss	SS 20033; DL
KE 44N11E-11.5g	Ascension Cemetery	IR	1926	695	1715	MS	C-O/MS	DL
KE 44N11E-16.2c	Libertyville "Second St."	P	1928-29	680	251	Sil	S & G	DL
KE 44N11E-18.4a	St. Mary of the Lake Sem. #3	P	1930	765	1919	MS	C-O/MS	DL
KE 44N11E-19.3b	Cardinal Stritch #2	P	1950	733	295	Maq	Sil Dol	SS 20809
KE 44N11E-24.4e	C. M. & St. P. RR.	I	1946	680	1107	Tr	G-SP/Tr	SS 15350; DL
KE 44N11E-24.2a	Knollwood C. Club	IR	1925	670	1602	EC	C-O	DL
KE 44N11E-27.1a	McDougal	R	1951	665	1005	G-SP	G-SP Ss	SS 21396
KE 44N11E-27.2b	Carpenter, Keith	R	1946	660	1000	G-SP	G-SP Ss	SS 18410; DL
KE 44N11E-35.4h	Dillon Subdivision	P	1931	708	1600	EC	C-O	SS 1105; DL
KE 44N11E-35.1d	Mrs. J. O. Armour Estate	IR	1929	702	1357	I-G	C-O	SS 876; DL
KE 44N11E-35.1a	Paul Llewellyn	R	....	688	1036	G-SP	G-SP Ss	SS 619; DL
KE 44N11E-35.6c	Elding	R	1951	663	995	G-SP	G-SP Ss	SS 21394; DL
KE 44N12E-6.1e	N. Shore Vista School	P	1952	725	1070	G-SP	G-SP Ss	SS 22675
KE 44N12E-9.4c	Dewey, C. E. #1	R	1939	645	1077	G-SP	G-SP Ss	SS 3351
E 44N12E-16.4h	Arden Shore Camp #3	P	....	655	964	G-SP	G-SP Ss	SS 1370 & 1510
E 44N12E-18.3a	Austin Deep Freeze #1	I	1951	678	1630	EC	C-O	SS 21463; DL
E 44N12E-21.6g	Methodist Orphanage	P	....	667	900	G-SP	G-SP Ss	DL
E 45N9E-9.2g	Fox Lake City	P	1927	770	945	G-SP	G-SP Ss	SS 676
E 45N10E-16.1b	Round Lake Golf Club	IR	1931	780	1056	G-SP	G-SP Ss	DL
E 45N10E-16.5a	Round Lake Beach (Shorewood)	P	1947	777	342	Sil	S & G	DL
E 45N10E-17.7h	Rd. Lake Beach (Indian Hills)	P	1948	770	174	Dr	S & G	DL
E 45N10E-26.7c	Wisconsin Cond. Milk Co.	I	1916	790	1040	G-SP	G-SP Ss	SS 6
E 45N10E-26.7b	Grays Lake City	P	1924	785	1323	EC	C-O	SS 411
E 45N10E-29.5h	Round Lake #3	P	1945	790	359	Maq	Sil Dol	SS 12701
E 45N11E-5.5c	F. S. Rickord #1 & 2	..	1929-30	750	1255	EC	C-O	SS 974
E 45N11E-23.4f	Gurnee High School	P	....	675	916	G-SP	G-SP Ss	DL
E 45N11E-29.8a	Wildwood Subdivision	P	1951	785	1310	EC	C-O	SS 21332
E 45N11E-32.7d	Johnson	R	1934	760	196	Sil	Sil Dol	DL
E 45N11E-34.1c	Wm. Bartholomay, Jr., Estate	R	1928	730	1672	MS	C-O/MS	DL
E 45N11E-36.4c	Duffield Farms	R	....	725	1008	G-SP	G-SP Ss	DL
E 45N12E-15.8e	Greiss-Pflager Tanning Co.	I	1928	588	1670	MS	C-O/MS	SS 726; DL
E 45N12E-33.4d	Abbott Laboratories	I	1921	655	1600	EC	C-O	DL
E 45N12E-33.2f1	Am. Steel & Wire #1	I	....	595	2153	MS	C-O/MS	DL
E 45N12E-33.2f2	Am. Steel & Wire #2	I	....	597	2058	MS	C-O/MS	DL

Well No. (*location*)	Owner	Use	Year drilled	Surface elevation above sea level	Depth (*ft.*)	Deepest formation reached	Main aquifer	Type of record
LKE 45N12E-33.2f3	Am. Steel & Wire #3	I	1891	597	2004	MS	C-O/MS	DL
LKE 46N10E-8.7c1	Antioch #1	P	1907	231	780	Dr	S & G	DL
LKE 46N10E-33.8a	Lake Villa #1	P	1937	294	798	Sil	S & G	SS 2281
LKE 46N11E-27.2a	Central Fur Farm Coop.	I	1957	673	1230	EC	C-O	SS 29299
LKE 46N11E-33.–	J. R. Simpson, Jr.	R	1932	680	1364	EC	C-O	SS 1265
LKE 46N12E-21.1a	Zion City #3	P	1935	629	995	G-SP	G-SP Ss	SS 1618; DL
LKE 46N12E-21.1b	Zion City #1	P	1925	631	1025	G-SP	G-SP Ss	SS 485; DL
LKE 46N12E-27.–	Beach State Park	P	1947	590	1002	G-SP	G-SP Ss	SS 17181
		McHENRY COUNTY						
MCH 43N7E-33.8h	Dean Milk Co.	I	1946	900	62	Dr	S & G	DL
MCH 43N8E-5.4g	Crystal Lake City	P	1930	915	2000	MS	C-O/MS	SS 902
MCH 43N8E-13.1g	Cary	P	1913	815	300	Sil	Sil Dol	DL
MCH 43N8E-21.1a	Material Service #1	I	....	835	1255	EC	C-O	SS 25854; DL
MCH 43N8E-28.5f	Lake in the Hills #4	P	1954	800	114	Sil	S & G	SS 25494; DL
MCH 43N9E-18.3a1	Fox River Grove	P	1928	738	145	Sil	Sil Dol	SS 695; DL
MCH 43N9E-18.3a2	Fox River Grove	P	1957	740	120	Sil	Sil Dol	SS 26965; DL
MCH 44N5E-35.5h	Arnold Engineering #1	I	1948	819	846	Fr	G-SP/Tr	SS 18763; DL
MCH 44N5E-35.3g	Borden Milk (Marengo)	I	1951	815	1028	EC	C-O	SS 21477; DL
MCH 44N7E-5.7d2	Woodstock City #2	P	1899	910	2079	MS	C-O/MS	DL
MCH 44N7E-5.7d3	Woodstock #3	P	1939	920	198	Dr	S & G	DL
MCH 44N8E-33.5a	Crystal Lake City	P	1953	929	1355	I-G	C-O	SS 22983
MCH 45N8E-26.5a	McHenry #6	P	1938	755	104	Dr	S & G	DL
MCH 46N5E-33.8a	Dean Milk, Chemung	I	1946	870	1783	MS	C-O/MS	SS 14396; DL
MCH 46N5E-35.2a	Bowman Dairy #2	I	1920	940	804	G-SP	G-SP Ss	DL
MCH 46N7E-8.1a	Hebron	P	1904	930	269	Dr	S & G	DL
MCH 46N8E-9.4f	Richmond #2	P	1956	819	146	Dr	S & G	SS 26359; DL
		WILL COUNTY						
WIL 33N9E-1.5e	Kankakee Ord. Works #5A	I	1942	570	1650	EC	C-O	SS 8207; DL
WIL 33N9E-10.8f	Fisher, W. #203	R	....	531	688	G-SP	G-SP Ss	DL
WIL 33N9E-12.1g	Kankakee Ord. Works #11	I	1942	575	1644	EC	C-O	DL
WIL 33N9E-22.8d	T. F. Anderson	R	....	554	635	G-SP	G-SP Ss	DL
WIL 33N9E-25.6b	Wilmington #2	P	1936	540	1566	I-G	C-O	SS 1830; DL
WIL 33N10E-9.4h	Elwood Ordnance	I	1941	640	1645	EC	C-O	DL
WIL 33N10E-9.1f	Elwood Ordnance	I	1941	647	1672	EC	C-O	DL
WIL 33N10E-10.5h	Elwood Ordnance #2	I	1941	642	834	PdC	G-SP Ss	SS 6357; DL
WIL 33N10E-16.2h	Elwood Ordnance #1	I	1941	643	803	PdC	G-SP Ss	SS 6356; DL
WIL 33N14E-15.7a	D. D. Van Voorhees #1	R	1933	695	1458	PdC	G-SP Ss	SS 1314; DL
WIL 34N9E-11.7g	Amoco Chemical #1	I	1957	571	1422	EC	C-O	SS 30479; D
WIL 34N9E-11.2e	Stepan Chemical #1	I	1955	542	1407	EC	C-O	SS 25945
WIL 34N9E-25.5a	Kankakee Ord. #8	I	1941	606	1627	EC	C-O	SS 6225; DL
WIL 34N9E-25.5d	Kankakee Ord. #9	I	1941	589	1603	EC	C-O	SS 6199; DL
WIL 34N9E-25.5h	Kankakee Ord. #10	I	1941	591	1571	EC	C-O	DL
WIL 34N9E-34.4a	Kankakee Ord. #3	I	1941	528	1593	EC	C-O	SS 5865; DL
WIL 34N9E-34.7a	Kankakee Ord. #4	I	1941	522	1551	EC	C-O	DL
WIL 34N9E-35.5a	Kankakee Ord. #1	I	1941	539	1597	EC	C-O	SS 5867; DL
WIL 34N9E-35.8a	Kankakee Ord. #2	I	1941	532	1612	EC	C-O	SS 5866; DL
WIL 34N9E-36.5b	Kankakee Ord. #6	I	1941	577	1653	EC	C-O	SS 6405; DL
WIL 34N9E-36.4e	Kankakee Ord. #7	I	1941	601	1655	EC	C-O	SS 6198; DL
WIL 34N10E-29.6g	Elwood City	P	1942	645	934	PdC	G-SP Ss	SS 7997; DL
WIL 34N10E-31.6a	Kankakee Ord. #12	I	1942	625	1710	EC	C-O	SS 7996; DL
WIL 34N11E-20.3g	Wabash RR.	I	1942	685	187	Sil	Sil Dol	DL
WIL 34N14E-8.1a	Crete #2	P	1924	725	264	Sil	Sil Dol	SS 533
WIL 35N9E-13.1c	Joyce 7-Up Co.	I	1940	627	725	G-SP	G-SP Ss	DL
WIL 35N9E-21.5a	Gardner #1	P	1943	584	960	G-SP	G-SP Ss	DL
WIL 35N9E-29.3f	Gaskill, E. #1	R	1954	580	565	G-SP	G-SP Ss	SS 24458; D
WIL 35N9E-32.4a	Connell, Ellen	R	1938	560	575	G-SP	G-SP Ss	DL
WIL 35N10E-2.8b	Joliet City	P	1924	555	1608	EC	C-O	SS 416; DL
WIL 35N10E-3.4e	Illinois State Pen. #3	P	1948	558	1600	EC	C-O	SS 18350; D
WIL 35N10E-4.1f	Calumet Chemical	I	1924	558	1596	EC	C-O	DL
WIL 35N10E-9.2e	Joliet City & Canal Div.	P	....	532	1570	EC	C-O	SS 98; DL
WIL 35N10E-9.1h	Joliet City, Ruby St.	P	1915	545	1560	EC	C-O	DL
WIL 35N10E-9.7f	St. Francis Convent	P	1937	648	943	G-SP	G-SP Ss	SS 2120; DL
WIL 35N10E-10.4b	Joliet Citizens Brewing Co.	I	1938	545	1483	PdC	G-SP Ss	SS 2815; DL
WIL 35N10E-10.7b	Joliet City, Van Buren St.	P	1913	540	1550	EC	C-O	SS 249; DL
WIL 35N10E-10.1a	Wm. E. Pratt Mfg. Co.	I	1943	550	795	G-SP	G-SP Ss	SS 9869; DL
WIL 35N10E-11.6g	E. J. & E. RR.	I	1950	558	1589	EC	C-O	SS 19958; D
WIL 35N10E-14.6h	Joliet City, Washington St.	P	1937	565	1608	EC	C-O	DL
WIL 35N10E-14.5e	Prairie State Paper Co.	I	....	585	1603	EC	C-O	DL
WIL 35N10E-15.8e	Joliet City, Spruce Slip	P	....	540	1530	EC	C-O	SS 320; DL
WIL 35N10E-16.2h	Joliet City, Des Plaines St.	P	....	540	1560	I-G	C-O	SS 248; DL
WIL 35N10E-16.5g	Joliet City, Jasper St.	P	1924	574	1565	EC	C-O	SS 417; DL

Well No. *(location)*	Owner	Use	Year drilled	Surface elevation above sea level	Depth *(ft.)*	Deepest formation reached	Main aquifer	Type of record
	WILL COUNTY—(Continued)							
WIL 35N10E-16.6a	U. S. Engineer's #1	I	1937	540	855	PdC	G-SP Ss	SS 2155; DL
WIL 35N10E-19.1f	American Can #2	I	1942	555	1594	EC	C-O	SS 7994; DL
WIL 35N10E-20.7g	Rockdale #2	P	1944-45	556	1586	EC	C-O	SS 11923; DL
WIL 35N10E-20.6a	Commonwealth Edison #2	I	1958	530	1494	EC	C-O	SS 30747; DL
WIL 35N10E-21.4b	American Cyn. & Chem. #2	I	....	583	1612	EC	C-O	SS 14684; DL
WIL 35N10E-22.3f	Will Co. TB San. #3	P	1944	615	865	PdC	G-SP Ss	SS 11111; DL
WIL 35N10E-22.7g	Amer. Inst. of Laundering #1	I	1929	562	1603	EC	C-O	DL
WIL 35N10E-29.8c	Blockson Chem. #5	I	1952-53	550	1535	EC	C-O	DL
WIL 35N10E-29.8g	Pub. Ser. Co. Sta. #9, Well #1	P	1940	530	1509	EC	C-O	DL
WIL 35N10E-30.1c	Blockson Chem. #4	I	1951	595	1555	EC	C-O	SS 20977; DL
WIL 35N10E-30.7e	Caterpillar #2	I	1950	545	1420	I-G	C-O	SS 20576; DL
WIL 35N11E-5.7d	Joliet Site #5, #2(?)	P	1951	670	1700	EC	C-O	SS 20836; DL
WIL 35N11E-5.7h	Joliet #6-1	P	1950	650	103	Dr	S & G	SS 20230
WIL 35N11E-5.7h	Joliet Site #6, #1	P	1949	645	1645	EC	C-O	SS 19944; DL
WIL 35N11E-8.8f	Joliet Site #5, #2	P	1950	655	1650	EC	C-O	DL
WIL 35N11E-13.6a	Mokena City Oil Test	..	1922	666	1085	PdC	....	SS 269; DL
WIL 35N11E-21.1c	McIntosh Sub.	P	1932	703	320	Sil	Sil Dol	SS 1296
WIL 35N12E-25.3e	J. R. McGlashan #1	..	1934	712	2700	MS	....	SS 1492
WIL 35N12E-28.1b	E. J. & E. RR.	I	1929	763	365	Maq	Sil Dol	SS 887; DL
WIL 36N9E-9.1g	Plainfield #1	P	1929	612	200	Sil	Sil Dol	DL
WIL 36N9E-10.8d	Plainfield #3	P	1956	608	1480	I-G	C-O	SS 26207; DL
WIL 36N9E-23.1h	E. L. Herren #1	R	1944	602	1958	MS	C-O/MS	SS 11831; DL
WIL 36N10E-2.7f	Pub. Ser. #1	P	1952	585	1505	EC	C-O	SS 22423; DL
WIL 36N10E-2.8h	Public Ser. #2	P	1952	585	1535	EC	C-O	SS 22424; DL
WIL 36N10E-16.4c	Globe Corp. Aircraft Div. #3	I	1953	668	1523	EC	C-O	SS 23494; DL
WIL 36N10E-23.6c	Lockport #2	P	1927	582	1475	EC	C-O	SS 707; DL
IL 36N10E-23.5a	Lockport #3	P	1940	662	1571	EC	C-O	SS 6680; DL
IL 36N10E-23.2f	Lockport #4	P	1954	648	1560	EC	C-O	SS 24934; DL
IL 36N10E-27.7b	Chicago Sanitary Dist.	P	1935	548	850	G-SP	G-SP Ss	SS 1704; DL
IL 36N10E-28.6h	Ill. State Pen. #3	P	1926	650	1527	I-G	C-O	DL
IL 36N10E-28.6f	Stateville #4	P	1936-37	640	2007	MS	C-O/MS	SS 1782; DL
IL 36N10E-29.6g	Stateville #5	P	1951	645	1535	I-G	C-O	SS 21217; DL
IL 36N10E-32.1a	Lidice City #3	P	1945	656	1652	EC	C-O	SS 14377; DL
IL 36N10E-33.6h	Public Ser., No. Ill.	P	1932	597	1558	EC	C-O	SS 1217; DL
IL 36N10E-33.5c	Chaney Sch. Dist. 88	P	1941	640	950	G-SP	G-SP Ss	DL
IL 36N10E-34.8a	Rubberoid Co.	I	1937	550	790	G-SP	G-SP Ss	SS 2043; DL
IL 36N11E-31.8a	Joliet Site #1, Well #3	P	1949	637	1656	EC	C-O	SS 19943; DL
IL 36N11E-32.4a	Joliet #3-5	P	1951	585	94	Dr	S & G	SS 22877
IL 37N10E-25.7b	Thiophene Prod. Co.	I	1930	585	1456	I-G	C-O	DL

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Preliminary Report on GROUND-WATER RESOURCES OF THE CHICAGO REGION, ILLINOIS

Max Suter, Robert E. Bergstrom
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SUMMARY

Preliminary Report on Ground-Water Resources of the Chicago Region, Illinois

**Max Suter, Robert E. Bergstrom, H. F. Smith,
Grover H. Emrich, W. C. Walton, and T. E. Larson**

This report is a summary of the essential findings of Cooperative Ground-Water Report 1 issued by the State Water Survey and the State Geological Survey. Report 1 discusses the geology and hydrology of the ground-water resources of the Chicago region, along with the history, present conditions, and effects of possible future development. Special emphasis is placed on the deep water-yielding formations, or aquifers, which have been most widely used for large ground-water supplies. Basic geologic, hydrologic, and chemical data applicable to local problems and to regional and long-range interpretations are presented to help formulate future policies regarding planning and development of water resources in northeastern Illinois.

INTRODUCTION

The Chicago region has been one of the most favorable areas for development of ground water in Illinois. It is underlain at depths of 500 feet and more by sandstone formations that have been prolific sources of water for nearly 100 years, and at lesser depths by water-yielding glacial deposits and creviced dolomite bedrock. However, the tremendous industrial and municipal growth in the region has brought about local problems of water supply, including considerable decline in artesian pressure of water from the deep formations.

The region described in this report includes Cook, DuPage, Kane, Kendall, Lake, and McHenry Counties, and parts of Grundy and Will Counties (fig. 1). The land area of 4,169 square miles is 7.5 percent of the state. The population of 5,979,800, estimated in 1957, amounts to 61.3 percent of the population of the state. Although the region contains 75 percent of the manufacturing establishments in Illinois, agriculture, transportation services, and mining and quarrying also contribute to its economic importance.

Largest user of water in the region is the city of Chicago, which serves about 60 municipalities with its water system and pumps more than a billion gallons a day from Lake Michigan. Some 110 municipalities not served by water from Lake Michigan obtain supplies from wells. Suburban and rural water supplies beyond municipal distribution systems are obtained from ground water. Many industries, including a large number of plants within the area served by water from Lake Michigan, have private wells and use ground water for processing and cooling.

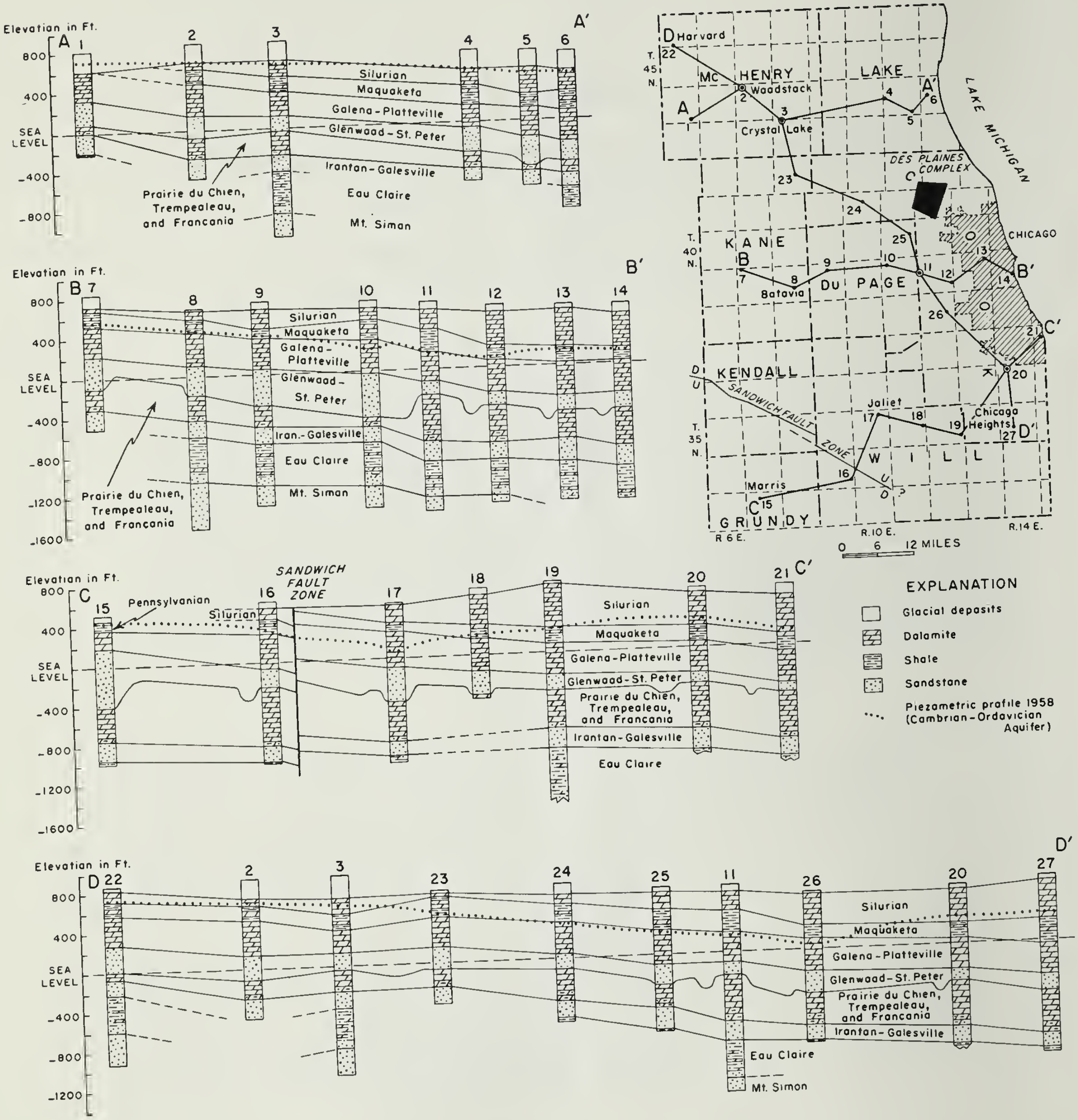


Fig. 1. Cross sections of the structure and stratigraphy of the bedrock and piezometric profile of the Cambrian-Ordovician Aquifer in the Chicago region.

GEOGRAPHY

The landscape of the Chicago region is varied, ranging from the low, flat Chicago lake plain on the east to the poorly drained, hilly belt of DuPage, Kane, Lake, and McHenry Counties to the west. The topography has been shaped primarily by glaciers that covered the region during the geologically recent Pleistocene Epoch, or Ice Age. Many of the ridges are accumulations of rock sediment that were deposited by ice along the margins of a glacier. These ridges, called moraines, are prominent features of the landscape.

Most of the region has an elevation of from 700 to 900 feet above sea level. The level of Lake Michigan is about 580 feet above sea level, and the highest point in the region, northeast of Harvard, has an elevation of 1192 feet. About 362 square miles of the region drain into Lake Michigan and the remaining 3807 square miles drain into the Mississippi River system, by way of the Kishwaukee, Rock, Illinois, Des Plaines, DuPage, Fox, and Kankakee Rivers.

The climate of the Chicago region is classified as continental with warm summers and cold winters. Precipitation, evaporation, and temperature - the most commonly measured climatic factors that are directly related to ground water - vary with the latitude. Aside from variations caused by local influences, such as Lake Michigan and the large urban area of Chicago, the average annual precipitation of the region for the period 1938-1957 ranges from about 32 inches in the north to about 35 inches in the southeast, and the average annual temperature ranges from about 48°F to 51°F.

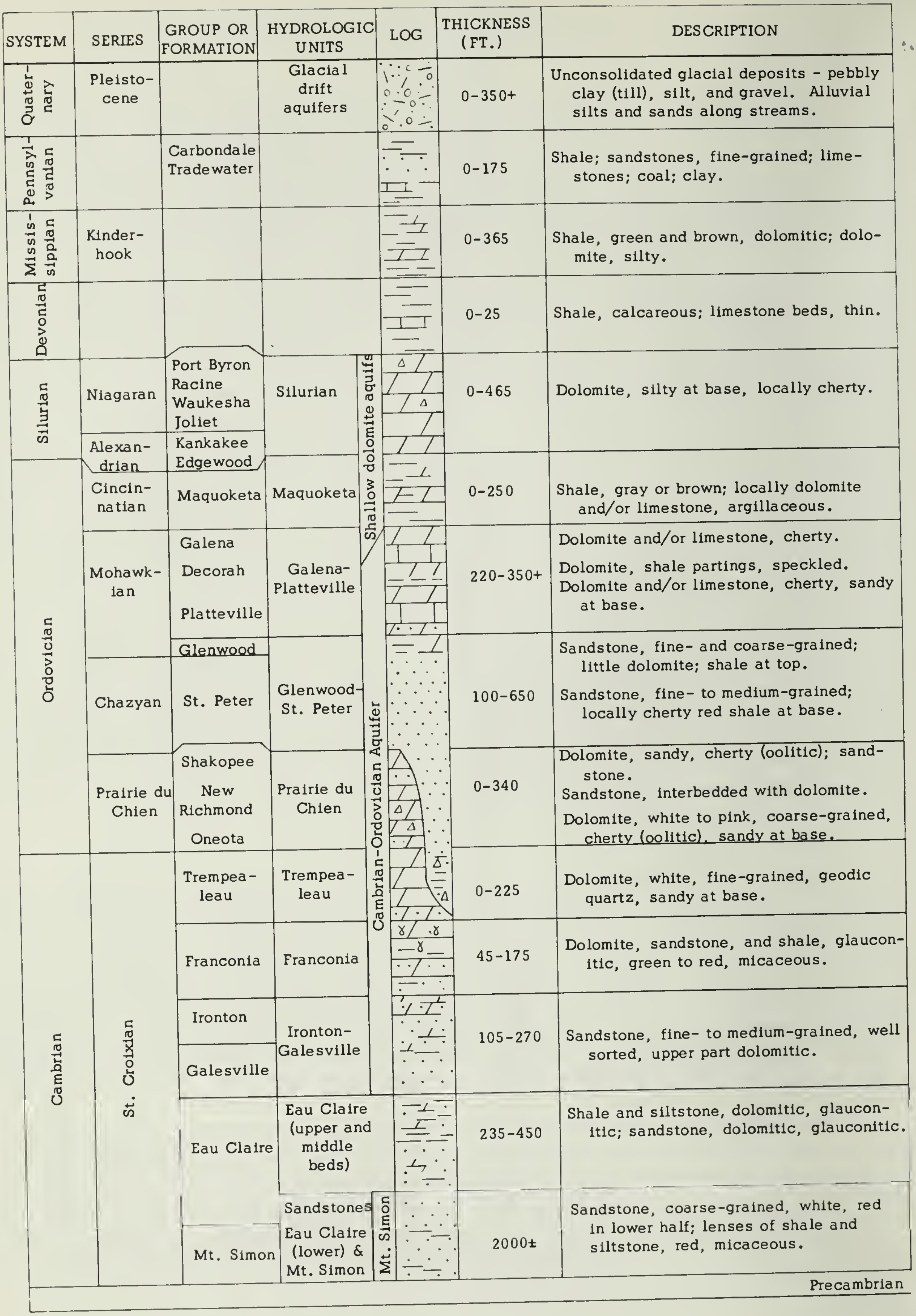
Climatic factors affect both the percolation of the precipitation into the ground-water reservoir, in the process called recharge, and the withdrawal of water by plants and man. In general, recharge in the Chicago region is greatest in the spring after the ground thaws and before vigorous plant growth begins. It has been estimated that about 10 to 12 percent of the annual precipitation reaches the ground-water reservoir in Illinois, and it is reasonable to believe that recharge in the Chicago region approximates this order of magnitude. Ground-water pumpage is related to temperature because ground water is widely used for air conditioning and for other cooling purposes.

GEOLOGY

The geologic nomenclature, characteristics, drilling and casing conditions, and water-yielding properties of the glacial drift, as well as the layered or sedimentary rocks of the region, are summarized in figure 2. The sequence, structure, and general characteristics of the rocks are shown in figure 1.

As shown in figure 2, ground-water resources in the region are developed from four aquifer systems: 1) sand and gravel deposits of the glacial drift; 2) shallow dolomite formations, mainly of Silurian age; 3) the Cambrian-Ordovician Aquifer, of which the Ironton-Galesville and Glenwood-St. Peter Sandstones are the most productive formations; and 4) the Mt. Simon Aquifer, consisting of the sandstone of the Mt. Simon and lower Eau Claire Formations.

The glacial drift and shallow dolomite aquifers are connected hydrologically. In most of the region these two aquifers are separated from the Cambrian-Ordovician Aquifer by the relatively water-tight or impermeable Maquoketa Formation, mainly shale, of Ordovician age. Impermeable beds in the middle and upper Eau Claire Formation separate the Cambrian-Ordovician Aquifer from the Mt. Simon Aquifer. The presence of beds that restrict the vertical circulation of ground water accounts for the difference in quality and pressures of waters in the various aquifers.



SYSTEM	SERIES	GROUP OR FORMATION	HYDROLOGIC UNITS		LOG	THICKNESS (FT.)	DESCRIPTION
Quaternary	Pleistocene		Glacial drift aquifers			0-350+	Unconsolidated glacial deposits - pebbly clay (till), silt, and gravel. Alluvial silts and sands along streams.
Pennsylvanian		Carbondale Tradewater				0-175	Shale; sandstones, fine-grained; limestones; coal; clay.
Mississippian	Kinderhook					0-365	Shale, green and brown, dolomitic; dolomite, silty.
Devonian						0-25	Shale, calcareous; limestone beds, thin.
Silurian	Niagaran	Port Byron Racine Waukesha Joliet	Silurian	Shallow dolomite aquifs		0-465	Dolomite, silty at base, locally cherty.
	Alexandrian	Kankakee Edgewood					
Ordovician	Cincinnatian	Maquoketa	Maquoketa			0-250	Shale, gray or brown; locally dolomite and/or limestone, argillaceous.
	Mohawkian	Galena Decorah Platteville	Galena-Platteville	Cambrian-Ordovician Aquifer		220-350+	Dolomite and/or limestone, cherty. Dolomite, shale partings, speckled. Dolomite and/or limestone, cherty, sandy at base.
		Glenwood	Glenwood-St. Peter			100-650	Sandstone, fine- and coarse-grained; little dolomite; shale at top. Sandstone, fine- to medium-grained; locally cherty red shale at base.
	Chazyan	St. Peter					
	Prairie du Chien	Shakopee New Richmond Oneota	Prairie du Chien			0-340	Dolomite, sandy, cherty (oolitic); sandstone. Sandstone, interbedded with dolomite. Dolomite, white to pink, coarse-grained, cherty (oolitic), sandy at base.
Cambrian	St. Croixian	Trempealeau	Trempealeau			0-225	Dolomite, white, fine-grained, geodic quartz, sandy at base.
		Franconia	Franconia			45-175	Dolomite, sandstone, and shale, glauconitic, green to red, micaceous.
		Ironton Galesville	Ironton-Galesville			105-270	Sandstone, fine- to medium-grained, well sorted, upper part dolomitic.
		Eau Claire	Eau Claire (upper and middle beds)			235-450	Shale and siltstone, dolomitic, glauconitic; sandstone, dolomitic, glauconitic.
		Mt. Simon	Sandstones Eau Claire (lower) & Mt. Simon	Mt. Simon		2000±	Sandstone, coarse-grained, white, red in lower half; lenses of shale and siltstone, red, micaceous.
							Precambrian

Fig. 2. Stratigraphy and water-yielding properties of the rocks,

DRILLING AND CASING CONDITIONS	WATER-YIELDING PROPERTIES	CHEMICAL QUALITY OF WATER	WATER TEMPERATURE °F
Boulders, heaving sand locally; sand and gravel wells usually require screens and development; casing required in wells into bedrock.	Sand and gravel, permeable. Some wells yield more than 1000 gpm. Specific capacities from 2.1 to 66 gpm/ft, av. 12 gpm/ft. Coefficient of trans. from 3400 to 100,000 gpd/ft, av. 25,000 gpd/ft.	McHenry County, hardness from 100 to 450 ppm., av. 275. Other counties, see Silurian below and text.	46° min. 52° av. 54° max.
Shale requires casing.	Jointed beds yield small supplies locally.		
	Limited areal extent; not used as aquifer.		
Upper part usually weathered and broken; extent of crevicing varies widely.	Not consistent; some wells yield more than 1000 gpm. Crevices and solution channels more abundant near surface. Specific capacities from 0.1 to 550 gpm/ft. Highest av. specific capacities (54.4 gpm/ft) in Du Page Co. wells, lowest (5 gpm/ft) in Lake Co. Coefficient of trans. averages 100,000 gpd/ft in Du Page Co., 9000 gpd/ft in Lake Co.	Variable. Hardness, <100 to >1000 ppm. Iron >0.3 ppm in 80% of analyses.	54°
Shale requires casing.	Shales, generally not water yielding, act as barriers between shallow and deep aquifers. Crevices in dolomite yield small amounts of water.		
Crevicing common only where formations underlie drift. Top of Galena usually selected for hole reduction and seating of casing.	Where formation lies below shales, development and yields of crevices are small; where not capped by shales, dolomites are fairly permeable.	Hardness < 100 ppm. H_2S often present.	54° to 55°
Lower cherty shales cave and are usually cased. Friable sand may slough.	Small to moderate quantities of water. Trans. probably about 15% of that of Cam.-Ord. Aquif.	Water similar in quality or slightly harder than that in Ironton-Galesville Sandstone.	53° to 56° 56° to 58° (Lake Co.)
Crevices encountered locally in the dolomite, especially in Trempealeau. Casing not required.	Crevices in dolomite and sandstone generally yield small amounts of water. Trempealeau locally well creviced and partly responsible for exceptionally high yields of several deep wells.		
Amount of cementation variable. Lower part more friable. Sometimes sloughs.	Most productive unit of Cam.-Ord. Aquif; trans. probably about 80% its total. Coefficients of trans. and storage of the Cam.-Ord. Aquif. av. 17,400 gpd/ft and 0.00035.	Hardness 200 to 250 ppm in northwest part of area, increasing toward east and south. Iron usually <0.4 ppm.	56° - 58° to 62° - 64°
Casing not usually necessary. Locally weak shales may require casing.	Shales, generally not water yielding, act as barrier between Ironton-Galesville and Mt. Simon.	Water soft in upper 100'; hardness increases downward (4000 ppm at elev. -2100'); chlorides 400 ppm at elev. -1600', increase at rate of 400 ppm each additional 25' depth.	66° at elev. -1300', increasing 1° with each additional 100' depth. Influenced by water from upper formations.
Casing not required.	Moderate amounts of water; permeability intermediate between that of Glenwood-St. Peter and Ironton-Galesville.		
crystalline rocks			

and character of the ground water in the Chicago region.

Glacial and Recent unconsolidated deposits overlie the much older layered bedrock in nearly all of the region (figs. 1 and 2). The bedrock surface on which the unconsolidated deposits lie was carved primarily by running water before the Pleistocene glaciers advanced across the region from the east and northeast. The bedrock surface slopes downward to the east and is scored by a system of valleys, some of which are completely buried by glacial deposits.

The glacial drift and Recent deposits range in thickness from a foot or less to more than 400 feet, the thicker drift occurring in the northwest part of the region and the thinner drift in Will, Grundy, and Cook Counties. The drift is made up of unsorted rock debris (till) deposited directly by the ice, sorted sand and gravel deposited by meltwaters at the border of the ice or in river channels (outwash), and fine sediments laid down in lakes and ponds. Sand and gravel outwash is the main source of ground water in the glacial drift. The tills and most lake sediments are so fine-grained that they permit little movement of ground water into a well. Deposits of sand and gravel occur locally at the surface or beneath other glacial materials; the thickest deposits of sand and gravel and those most productive of water are in valleys cut into the bedrock.

Beneath the glacial deposits, the bedrock formations, consisting mainly of beds of dolomite (a limestone-like rock), sandstone, and shale, have a regional dip of about 10 feet per mile toward the southeast (fig. 1). The rocks are warped into gentle folds that generally trend in the direction of the regional dip. In some places the rocks are broken and displaced along faults. The Sandwich Fault zone, along which more than 150 feet of displacement occurs locally, crosses the southwest part of the region. Complex faulting occurs in an area of about 25 square miles at Des Plaines. There is no indication that the folds or the faults act as barriers to the regional movement of ground water, but locally they modify its occurrence and movement.

Silurian age dolomite (figs. 1 and 2), which contains ground water in crevices and solution channels that locally yield very large supplies, underlies the drift and overlies the Maquoketa Formation in most of the region. Below the Maquoketa Formation, beds of sandstone generally alternate with beds of dolomite and shale (fig. 2).

The sandstones - Glenwood-St. Peter, Ironton-Galesville, and Mt. Simon-lower Eau Claire - store water and transmit it readily through the tiny pores between sand grains and are thus said to be permeable. From the early days they have been well known as artesian aquifers. The Ironton-Galesville Sandstone is the most consistently permeable and productive formation in the bedrock, though locally the Silurian age dolomite is so highly creviced that it yields much larger quantities of ground water. The Glenwood-St. Peter Sandstone is less permeable than the Ironton-Galesville Sandstone and is of secondary importance as an aquifer. The Mt. Simon Aquifer is also of lesser importance than the Ironton-Galesville Sandstone as a source of water because it is deeper, it contains highly mineralized water in many areas, and it is less consistently permeable.

Below the layered sedimentary rocks, Precambrian crystalline rocks such as granite form a relatively impermeable basement at depths from 3000 to 5000 feet below the surface.

GROUND-WATER PUMPAGE

Pumpage of ground water in the region has generally increased through the years, though pumpage in the Chicago metropolitan area is somewhat less than it was in the peak year of 1924 just before many of the industries of the area abandoned their wells in favor of water supplies from Lake Michigan. Between 1948 and 1957 ground-water pumpage by municipalities in the Chicago region increased 70 percent. Pumpage from deep wells alone has increased from 200,000 gallons per day (gpd) in 1864 to an estimated 76 million gallons per day (mgd) in 1958. Figure 3 shows the estimated pumpage from deep wells for the period from 1864 to 1958.

Total ground-water pumpage from all sources in the region in 1957 was 127.9 mgd, of which 72.4 mgd were from deep wells penetrating the Cambrian-Ordovician Aquifer and locally the Mt. Simon Aquifer, 41.2 mgd were from wells finished in the shallow dolomite, and 14.2 mgd were from wells finished in the glacial drift. It is estimated that about 27 percent of the water pumped from deep wells actually came from the shallow dolomite or glacial drift aquifers, thus making the present yield of the shallow aquifers about 60 percent of the total pumpage in the region.

About 78.9 mgd were pumped for public supplies in 1957, including supplies for municipalities and institutions; 35.2 mgd were for industrial supplies; 13.1 mgd were for rural, non-irrigation supplies; and 0.6 mgd were for irrigation supplies for farms, golf courses, and cemeteries. In general, municipalities with large pumpage obtain water from the deep aquifers, those with small pumpage obtain water from glacial drift aquifers, and those with intermediate pumpage obtain water from the shallow dolomite aquifers.

Cook County with 48.4 mgd, Will County with 22.8 mgd, DuPage County with 21.5 mgd, and Kane County with 20.8 mgd account for almost 90 percent of the total pumpage in the region. Southeastern DuPage County and the adjacent part of Cook County are the areas of heaviest pumpage from the shallow aquifers, and the areas of heaviest pumpage from the deep aquifers are around Aurora, central Cook County, and Joliet.

HYDROLOGY OF AQUIFERS

Cambrian-Ordovician and Mt. Simon Aquifers

Ground water in the Cambrian-Ordovician and Mt. Simon Aquifers is confined under artesian pressure and therefore, in the deep wells, rises above the top of the aquifers. The first deep well drilled at Chicago in 1864 flowed at a rate of about 200,000 gpd with a head of 80 feet above land surface, or to an elevation of 695 feet above sea level. In 1864 the artesian pressure in the Cambrian-Ordovician Aquifer was at elevations of about 690 feet at Joliet, between 700 and 750 feet along the Fox River Valley and between 750 and 850 feet in McHenry, Kane, Boone, and DeKalb Counties.

Elevations to which ground water rises in artesian wells form an imaginary pressure surface, called the piezometric surface. In 1864, the piezometric surface of the Cambrian-Ordovician Aquifer sloped southeast from a ground-water ridge or area of higher artesian pressures in Boone, McHenry, Kane, and DeKalb Counties. The low natural slope (hydraulic gradient) of the piezometric surface, about 2 feet per mile, was sufficient to transmit only about 900,000 gpd from the ground-water ridge toward Chicago. Water entering or recharging the aquifer in Boone, DeKalb, and McHenry Counties was discharged naturally in areas to the east and south by slow leakage upward through the confining Maquoketa Formation and by leakage into the Illinois River Valley.

Pumpage from the deep aquifers after 1864 created depressions in the artesian pressure surface around individual wells and groups of wells. These depressions,

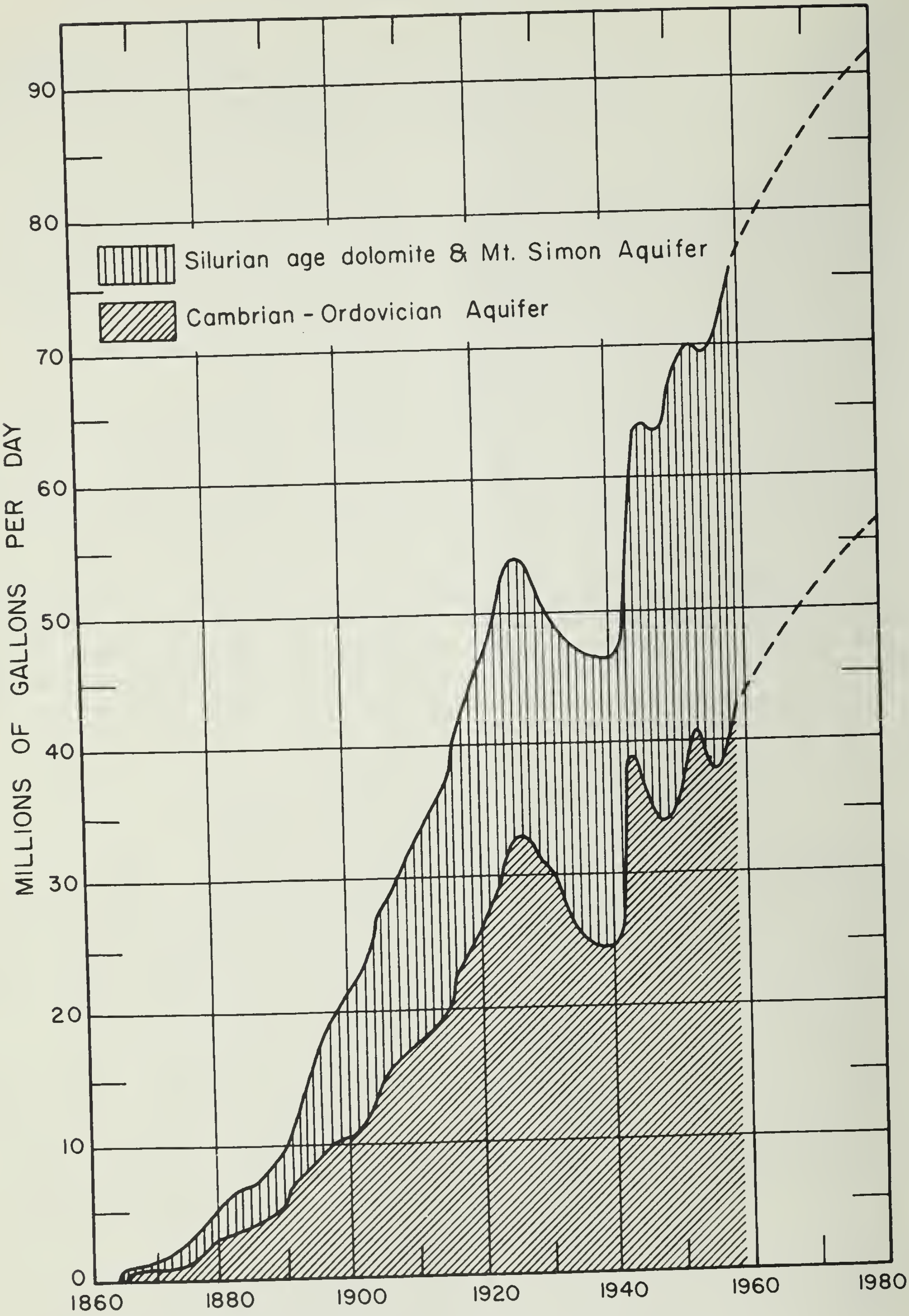


Fig. 3. Pumpage from deep wells, 1864 to 1958, and estimated pumpage to 1980, subdivided by source.

because they are in the approximate form of an inverted cone, are called cones of depression. Under conditions of pumpage at a constant rate, a cone of depression grows at a decreasing rate, as time goes on, until 1) the lowering of artesian pressure results in increased recharge to, or decreased natural discharge from, the aquifer (or a combination of the two effects), and 2) hydraulic gradients are established which bring from recharge areas the amount of water pumped. In the Chicago region, however, the cones of depression did not stabilize because pumpage rates did not remain constant. Instead, after 1864 withdrawals in several areas within the region increased progressively (fig. 3), cones of depression overlapped and spread out in all directions, and the artesian pressure declined at an increasing rate throughout most of the period of development. The table below shows the distribution of pumpage from deep wells in 1958.

Pumping Center	Total Pumpage in mgd
Chicago Area	23.4
Joliet Area	14.0
Elmhurst Area	9.8
Des Plaines Area	6.8
Elgin Area	8.1
Aurora Area	14.0
	76.1

Many deep wells in the Chicago region are either uncased or faultily cased in the Silurian age dolomite and allow leakage. The Mt. Simon Aquifer also is penetrated by a large number of deep wells, particularly along the Fox River in Kane County. The artesian pressure of the Cambrian-Ordovician Aquifer is much lower than that in the Silurian age dolomite and Mt. Simon Aquifer. Ground water therefore moves downward from the dolomite and upward from the Mt. Simon into the Cambrian-Ordovician Aquifer through wells that are open in all three aquifers. Thus, water pumped from deep wells does not come from the Cambrian-Ordovician alone. The amounts of water derived from Silurian age dolomite and the Mt. Simon Aquifer and the Cambrian-Ordovician Aquifer between 1864 and 1958, shown in figure 3, were estimated by studying piezometric-surface maps and data on mineral content and temperature of water, and by evaluating the number, yield, and time of construction of wells open in the various aquifers. Of the 76.1 mgd pumped from deep wells in 1958, 20.5 mgd came from the Silurian age dolomite and 12.8 mgd came from the Mt. Simon Aquifer.

Decline in Artesian Pressure

The changes in artesian pressure produced by pumping since the days of early settlement have been pronounced and widespread. As early as 1895 the artesian pressure had declined about 150 feet at Chicago, 100 feet at Joliet, and 50 feet along the Fox River Valley. By 1915 the artesian pressure had declined, in response to continual increases in withdrawals of water, to elevations of 400 feet above sea level at Chicago and at Joliet. In 1958 the artesian pressure was at elevations of about 50 feet at Chicago and 25 feet at Joliet.

Figure 4 shows the decline of artesian pressure in the Cambrian-Ordovician Aquifer from 1864 to 1958. The greatest declines, more than 600 feet, have occurred

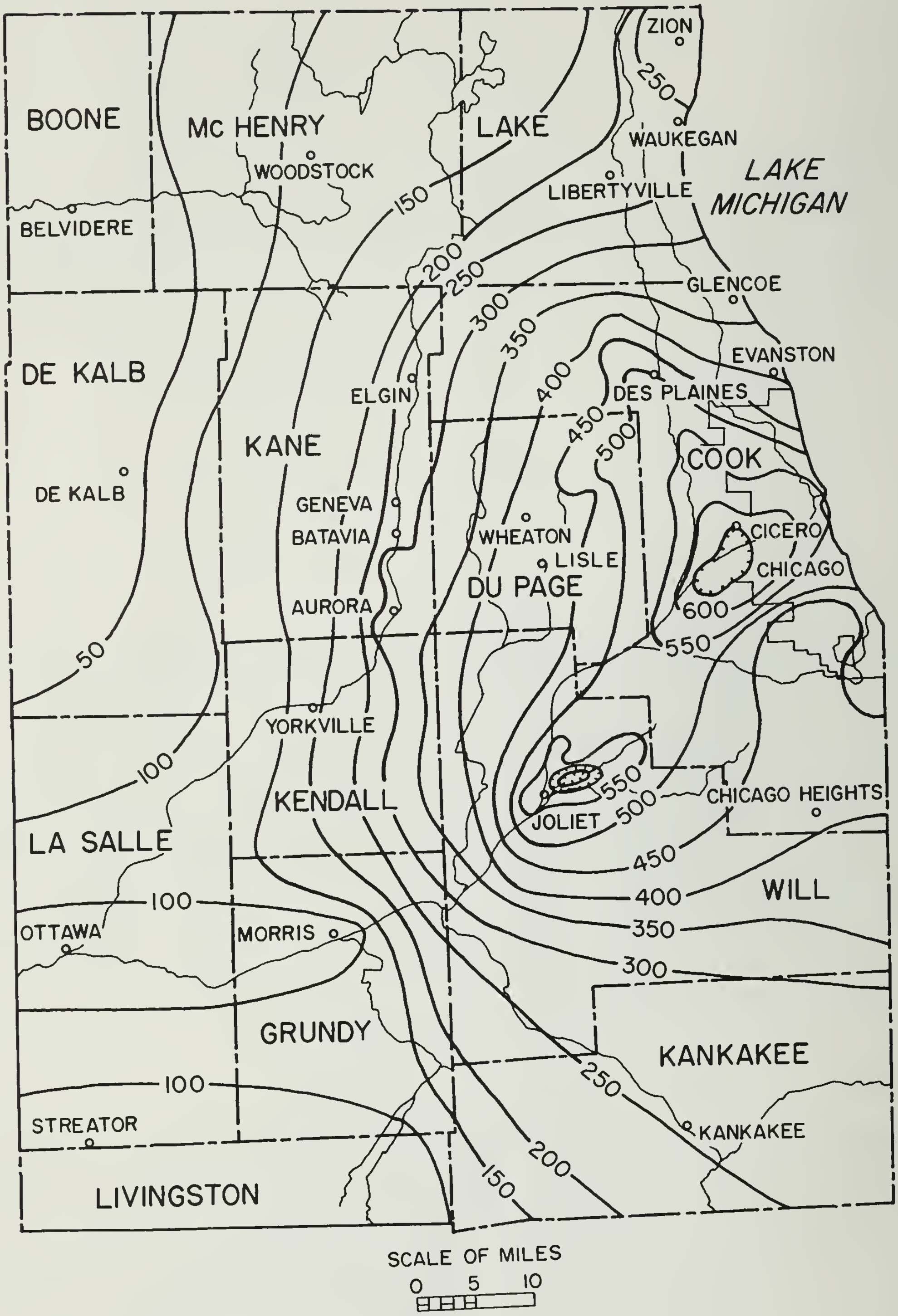


Fig. 4. Decline, in feet, of artesian pressure in Cambrian-Ordovician Aquifer from 1864 to 1958.

in areas of heavy pumpage west of Chicago, at Summit, and at Joliet (note wells 26 and 17, fig. 1). The average rate of decline in the Chicago area, 1864 to 1958, was about 7 feet per year. The artesian pressure has declined about 500 feet at Des Plaines and Elmhurst and about 275 feet along the Fox River Valley. The decline has been least, 10 feet or less, in areas in DeKalb, Boone, and McHenry Counties. Most of the decline in areas in these three counties is due to local pumpage and cannot be attributed to heavy pumping in the Chicago region.

It is estimated that about 340 billion gallons of water were taken from storage within the aquifer during the period 1864 to 1958. The water taken from storage is derived by compaction of the aquifer and by expansion of the confined water itself. The average volumetric rate of decrease in ground-water storage during the period 1949-58 was about 23 mgd.

The general pattern of flow of water through the Cambrian-Ordovician Aquifer at present is slow movement from all directions toward the deep cones of depression centered near Chicago and at Joliet. Some of the water flowing toward Chicago and Joliet is intercepted by cones of depression in the Aurora, Elgin, Des Plaines, and Elmhurst areas.

Geohydrologic Boundaries

Certain geologic conditions and surface hydrologic features have the effect of limiting the growth of the cone of depression or the lateral extent of the Cambrian-Ordovician Aquifer so that the influence of these features (geohydrologic boundaries) must be taken into account in computing drawdowns in wells under past or future conditions. Recharge boundaries occur where an aquifer receives replenishment. Boundaries across which the flow of ground water is prohibited or retarded are called barrier boundaries.

The profiles (fig. 1) and maps of the piezometric surface of the Cambrian-Ordovician Aquifer show high elevations and a ground-water ridge in McHenry, Boone, and DeKalb Counties, indicating recharge in these areas. The high elevations in McHenry and Boone Counties extend into Wisconsin. The piezometric surface reaches crests mostly in areas where the Galena-Platteville Dolomite crops out at the surface or is the uppermost bedrock formation below the glacial deposits. Here the Galena-Platteville Dolomite is well creviced and affords a good hydraulic connection between the Glenwood-St. Peter Sandstone and glacial deposits.

The Ironton-Galesville Sandstone receives water from the Glenwood-St. Peter Sandstone through crevices and other openings in the intervening dolomites (fig. 2). Recharge to the Glenwood-St. Peter Sandstone and eventually to the Ironton-Galesville Sandstone takes place generally through fractures and solution channels in the Galena-Platteville Dolomite, which in turn receives water from the overlying glacial deposits. Recharge of the glacial deposits occurs from precipitation that falls locally. The distribution of sulfates in and the temperature of water from the Cambrian-Ordovician Aquifer, and the map showing decline in artesian pressure (fig. 4) indicate approximately the same areas of recharge as do profiles (fig. 1) and maps of the piezometric surface.

It is estimated that in 1958 about 18 mgd of ground water were transmitted from recharge areas in northeastern Illinois and about 2 mgd were transmitted from recharge areas in southeastern Wisconsin toward cones of depression in the Chicago region. It is probable that a small amount of recharge occurs directly through the Maquoketa Formation and from the Illinois River Valley under the influence of extensive and deep cones of depression in the Cambrian-Ordovician Aquifer. Available data suggest that the recharge effect of Lake Michigan is negligible.

Deep wells in Kankakee County and near the Indiana state line have small yields, indicating that the ability of the aquifer to transmit water decreases rapidly south of Joliet and east of Chicago. Thus, the Cambrian-Ordovician Aquifer is enclosed by barrier boundaries to the east and south and by one recharge boundary to the west. The barrier boundaries increase drawdown in wells and the recharge boundary decreases drawdown in wells.

The results of geologic and hydrologic studies in northern Illinois indicate that the effects of the geohydrologic boundaries on wells in the Cambrian-Ordovician Aquifer can be simulated by mathematical analysis of a hypothetical hydrologic model. The hydrologic model consists of a rectangular aquifer 84 miles in width enclosed by a recharge boundary 47 miles west of Chicago and by two intersecting barrier boundaries 37 and 60 miles east and south of Chicago. The water-yielding properties of the aquifer, that is its ability to transmit water and to release water from storage, were determined from the results of 63 pumping tests. These properties are summarized in figure 2.

Potential Ground-Water Development and Its Effects

According to an estimate based on the past rate of increase of pumpage (fig. 3), and on the assumption that the total pumpage from deep wells in the Chicago region will increase at a fairly uniform rate from 76 mgd in 1958 to about 92 mgd in 1980, about 56 mgd will be withdrawn from the Cambrian-Ordovician Aquifer in 1980. Declines in nonpumping water levels that may be expected between 1958 and 1980 at Chicago, Joliet, Des Plaines, Elmhurst, Elgin, and Aurora are presented in the table below. The nonpumping water level is the level at which water stands in a well that is not influenced by pumping in the immediate vicinity of the well.

Pumping Center	1958 Nonpumping water level in feet above sea level	1958-1980 Computed future water level decline in feet	1980 Predicted nonpumping water level in feet above (+) or feet below (-) sea level
Chicago Area	50	300	-250
Joliet Area	20	220	-200
Elmhurst Area	150	250	-100
Des Plaines Area	200	300	-100
Elgin Area	490	190	+300
Aurora Area	400	250	+150

Declines were computed by using the hydrologic model described earlier and assuming that the distribution of pumping remains the same as it was in 1958. By 1980 the Galena-Platteville Dolomite and the Glenwood-St. Peter Sandstone will be partially dewatered in parts of the Chicago region, and the specific capacities (yields per foot of drawdown) of deep wells will probably decrease about 10 percent.

Practical Sustained Yield

Aside from economic considerations and quality of water, the practical sustained yield of the Cambrian-Ordovician Aquifer is limited, not by the rate of replenishment in recharge areas, but by the rate at which water can move eastward through the aquifer from recharge areas. It is estimated that the recharge area of the Cambrian-Ordovician Aquifer that affects the Chicago region is about 1200 square miles. If five percent of the average annual precipitation infiltrates into the aquifer in the recharge areas, a conservative figure, the total water available at the recharge areas is about 100 mgd. However, computations assuming a large number of uniformly and widely spaced wells show that the maximum quantity of water that could be transmitted from recharge areas to the Chicago region is only about 65 mgd. Because pumping is not distributed in this ideal manner, development of the full calculated capacity of the aquifer, 65 mgd, is impossible.

The practical sustained yield of the aquifer is the maximum amount of water that can be withdrawn without eventually dewatering the most productive water-yielding formation, the Ironton-Galesville Sandstone. If it is assumed that the distribution of pumpage remains the same as in 1958, the practical sustained yield is estimated to be about 46 mgd. This yield will be developed when the total pumpage from deep wells is about 81 mgd. According to figure 3, the practical sustained yield will be exceeded in about 1965. If pumpage increases to a total of 46 mgd and then remains the same, the nonpumping water level in Chicago will eventually decline to a position about 100 feet above the top of the Ironton-Galesville Sandstone and at an elevation of about 650 feet below sea level. Pumping levels in wells, if the present rates of pumping from individual wells are maintained, would be within a few feet of the top of the Ironton-Galesville Sandstone.

Shallow Dolomite and Glacial Drift Aquifers

Water levels in the shallow dolomite and glacial drift aquifers vary greatly from time to time and place to place; however, at no location is there any apparent permanent decline. The greater part of the pumpage is from the shallow dolomite aquifers in DuPage and Cook Counties. Records of water levels in these counties indicate that the potential yield of the shallow dolomite aquifer is much greater than present withdrawal rates.

The glacial drift aquifers are used as sources of municipal and industrial groundwater supplies at relatively few locations. The largest development is northeast of Joliet. Five gravel wells owned by the city of Joliet produce 650 gpm each. Several areas favorable for sand and gravel wells are presently undeveloped. Present withdrawals from the glacial drift aquifers are probably much less than their potential yield.

Geologic and hydrologic data indicate that the average water-yielding capacities of the shallow dolomite and glacial drift aquifers are greater than those of the Cambrian-Ordovician Aquifer.

QUALITY OF GROUND WATER

Ground waters in the Chicago region vary in mineral quality between the various producing aquifers and also within individual aquifers at different locations. Below an elevation of 1300 feet below sea level, ground water in the deep aquifers is too highly mineralized for most uses. The chemical characteristics and temperatures of waters from the various aquifers are summarized in figure 2.

In general, temperatures of waters increase downward, from an average of 52°F in the glacial drift to 66°F in the Mt. Simon Aquifer at an elevation of 1300 feet below sea level, with higher temperatures below. Within the Cambrian-Ordovician Aquifer the temperatures increase to the east as the aquifer gets deeper.

Ground waters in the glacial drift and shallow dolomite aquifers are similar in quality. The hardness ranges from 100 to 450 parts per million (ppm) and the sulfate and chloride concentrations are low. Locally the waters in the glacial drift and shallow dolomite aquifers have a hardness of more than 1000 ppm. The iron content is significant in 80 percent of the wells.

The mineral quality of the water from the Cambrian-Ordovician Aquifer is relatively uniform in the western two-thirds of the region, with a hardness in the range of 200 to 250 ppm and chloride and sulfate content somewhat higher than in water from the shallow aquifers. Mineralization increases sharply east of DuPage County and south of Joliet to 800 ppm hardness, 400 ppm chlorides, and 800 ppm sulfates near the Indiana state line. The iron content is low.

Because mineral content, particularly hardness and chlorides, of water in the Mt. Simon Aquifer increases rapidly with depth below an elevation of 1275 feet below sea level, drilling below the base of the Ironton-Galesville Sandstone is not recommended in the southeastern third of the region.

CONCLUSIONS AND RECOMMENDATIONS

The present withdrawals from the shallow aquifers are far less than the potential yields of these aquifers, whereas withdrawals from the Cambrian-Ordovician Aquifer have already approached the sustained yield. The shallow aquifers are the most likely sources to investigate for additional ground-water supply. These aquifers are more readily recharged than the Cambrian-Ordovician Aquifer and locally have high water-yielding capacities. Existing data indicate that the undeveloped ground-water resources of the shallow aquifers are large, although their sustained yield is undetermined.

Not enough data are available to permit estimating a water resources budget for the Chicago region. Many additional geologic, hydrologic, meteorologic, and engineering observations, measurements, calculations and methods bearing on both ground water and surface water are needed. With respect to ground water, the following investigations are recommended:

1) Study of the shallow aquifers to determine their potential yield and to locate areas favorable for ground-water development.
2) Regional study of the Cambrian-Ordovician and Mt. Simon Aquifers to determine water-yielding capacities of individual units.
3) Study of the possible effects of dewatering the Cambrian-Ordovician Aquifer.
4) Study of possible recharge of the aquifers from Lake Michigan.
5) Study of the relations between the Chicago and Milwaukee pumpage cones.
6) Study of well and aquifer characteristics during and after well construction.
7) Collection of more complete data on pumpage, particularly from shallow aquifers.

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Arthur J. Zeizel
William C. Walton
Robert T. Sasman
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GROUND-WATER RESOURCES OF DUPAGE COUNTY, ILLINOIS

ARTHUR J. ZEIZEL, WILLIAM C. WALTON,
ROBERT T. SASMAN, and THOMAS A. PRICKETT

ABSTRACT

A rapidly increasing development of ground-water resources in DuPage County, Illinois, has resulted from the municipal and industrial growth in the Chicago metropolitan region. Evaluation of the ground-water resources of DuPage County provides a basis for their development and management.

Ground-water supplies are withdrawn from four principal geohydrologic units: 1) glacial drift aquifers, 2) Silurian dolomite aquifer, 3) Cambrian-Ordovician aquifer, and 4) the Mt. Simon aquifer. The glacial drift and Silurian dolomite aquifers receive recharge chiefly from precipitation that falls within the county limits. Relatively impermeable shales of the Maquoketa Formation separate these aquifers from the deeper Cambrian-Ordovician aquifer. Recharge to the Cambrian-Ordovician aquifer occurs in the areas of Kane, McHenry, Kendall, Boone, and DeKalb Counties where the Maquoketa Formation is appreciably dolomitic, relatively thin, or absent. The water moves southeastward from these recharge areas through the aquifer toward a deep cone of depression centered near Summit in Cook County.

The total potential yield of the glacial drift and Silurian dolomite aquifers is calculated to be 41 million gallons per day (mgd); the calculated potential yield of the Silurian dolomite aquifer (38 mgd) is limited by recharge. Full development of the underlying Silurian dolomite aquifer is assumed in estimating the potential yield of the glacial drift aquifers (3 mgd), and the yield of the glacial drift aquifers is considered as supplemental to the yield of the Silurian dolomite aquifer. Practical sustained yields of the deeper Cambrian-Ordovician and Mt. Simon aquifers are calculated to be 4.3 mgd and 2.1 mgd respectively.

Water levels in wells in the Cambrian-Ordovician aquifer in some areas have declined as much as 635 feet since 1864, and the average decline over the county during the 96-year period (1864 to 1960) was about 480 feet. Total withdrawals from the Cambrian-Ordovician and Mt. Simon aquifers in 1960 (8.8 mgd) exceeded the calculated total practical sustained yield of these aquifers (6.4 mgd).

The Silurian dolomite aquifer is the most heavily developed source of ground water in DuPage County and yielded 68 percent of the 29.3 mgd pumped from all aquifers in 1960. The calculated practical sustained yield of this aquifer (35 mgd) exceeded total withdrawals in 1960 and nonpumping water levels were not critical in any pumping center in the county. Extrapolation of pumpage graphs shows that the practical sustained yields of some pumping centers will be exceeded within 2 to 5 years and the practical sustained yields of all pumping centers will be exceeded by 1985. Extrapolation of the pumpage growth curve for the county shows that total ground-water withdrawals from wells will exceed the potential yield of the Silurian dolomite aquifer by about 1977.

INTRODUCTION

Purpose and Scope

This report presents a quantitative evaluation of the round-water resources of DuPage County, Illinois, and as prepared cooperatively by the Illinois State Geogical Survey and the Illinois State Water Survey. he geohydrologic characteristics of the ground-water servoir beneath the county are given along with an alysis of past, present, and probable future development of the ground-water resources. Special attention given to the Silurian dolomite aquifer and the associed glacial drift aquifers because of their potential as urces of ground water. The importance of these aquirs is emphasized by the rapidly increasing demands r water supply and the widespread continuing decline of water levels in the deeper Cambrian-Ordovician aquifer. The maps, data, and interpretations presented provide a basis for water-resource planning and a guide to the development and conservation of ground water in the county.

Detailed study in DuPage County was begun in 1957 as part of a research program of the State Geological Survey on geologic factors controlling ground water in the Silurian dolomite aquifer in northeastern Illinois. The need for an evaluation of the ground-water resources of DuPage County was recognized in 1959 and cooperative investigation by the State Geological Survey and the State Water Survey was initiated. The State Water Survey collected data on water levels, pumpage, mineral quality of water, and well tests. Well logs, drilling samples, geophysical logs, and other geologic information were provided by the State Geological Survey.

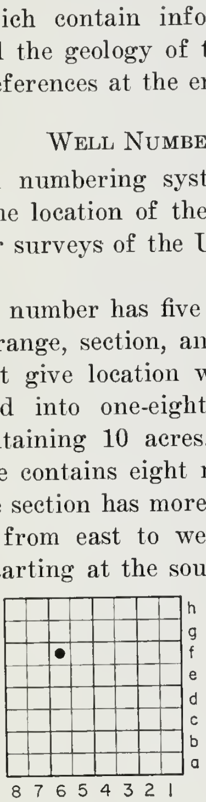
Previous Reports

General information on the ground-water resources of DuPage County is included in reports on: *The Artesian Waters in Northeastern Illinois* (Anderson, 1919), *The Groundwater Possibilities in Northeastern Illinois* (Bergstrom et al., 1955), and *Preliminary Report on Ground-Water Resources of the Chicago Region, Illinois* (Suter et al., 1959). Other published and unpublished reports which contain information on the water resources and the geology of the county are listed in the Selected References at the end of this report.

Well Numbering System

The well numbering system used in this report is based on the location of the well and on the system of rectangular surveys of the U. S. Government for identification.

The well number has five parts: county abbreviation, township, range, section, and coordinates (number and letter) that give location within the section. Sections are divided into one-eighth mile squares with each square containing 10 acres. A normal section of one square mile contains eight rows of eighth-mile squares: an odd-size section has more or fewer rows. Squares are numbered from east to west and lettered from south to north starting at the southeast corner as illustrated:



DuPage County
T39N, R9E,
sec. 30

The well number of the well shown is DUP 39N9E-30.6f. When more than one well is in a 10-acre square they are identified by arabic numbers after the lower case letter in the well number.

Acknowledgments

The basic geologic and hydrologic data upon which this report depends were provided through the cooperation of many county, municipal, and industrial officials, engineers, water-well contractors, and well owners. Special thanks are due Orville L. Meyer, former Chie Engineer of the DuPage County Health Department for the many valuable logs of water wells made available during the investigation.

The U. S. Geological Survey supplied logs, hydrographs of wells, and pumping test data from Argonn National Laboratory and arranged for the loan of th deep-well current meter used in the geophysical investigation. The Illinois Division of Waterways installe and furnished data from stream gages.

The geological and geophysical studies incorporate in this report were conducted by the State Geologica Survey. Discussion of the units below the Maquoket Formation has been modified for DuPage County from Cooperative Ground-Water Report 1 (Suter et al., 1959) The hydrologic and water chemistry studies were mad by the State Water Survey.

Arthur J. Zeizel, of the State Geological Survey, wa responsible for the processing and analysis of the geologic and geophysical data and assisted in geohydrologi interpretations. The authors of the State Water Surve participated in the following manner: William C. Walton supervised computation and analysis of the hydrologic and chemical data and assisted in geohydrologi interpretations; Robert T. Sasman collected, processed and analyzed water level and pumpage data; Thomas A Prickett processed and aided in the analysis of basi hydrologic data, made most of the hydrologic computations, and assisted in geohydrologic interpretations.

Many present and former members of both agencie have assisted in the preparation of the report and i the collection and processing of data. Among these ar George B. Maxey, James E. Hackett, Robert E. Bergstrom, Grover H. Emrich, Francis Wobber, Lowell A Reed, and Richard Cannon of the staff of the Geologica Survey and Harmon F. Smith, Jacob S. Randall, Richard J. Schicht, George E. Reitz, William H. Bake Sandor Csallany, Robert R. Russell, and W J Woo of the Engineering staff of the State Water Survey.

The chemical analyses of water from wells were mad by the Chemistry Section of the Water Survey. Section on climate and statistical analysis of geologic control were prepared, in large part, by Stanley A. Changno and James C. Neill, respectively, both of the Wate Survey.

GEOGRAPHY

Location and General Features

DuPage County is in the northeastern part of Illinois (fig. 1). It is about 18 miles square, has an area of 331 square miles, and includes all of townships 38 to 40 north, ranges 9 to 11 east, and part of township 37 north, range 11 east (figs. 2 and 3). It is bounded on the north and east by Cook County, which contains th city of Chicago, on the south by Will County, and o the west by Kane County. Quadrangle topographi maps, published by the U. S. Geological Survey, cove the area (pl. 1, *in pocket*).

In 1950 about 60 percent of the land in DuPag

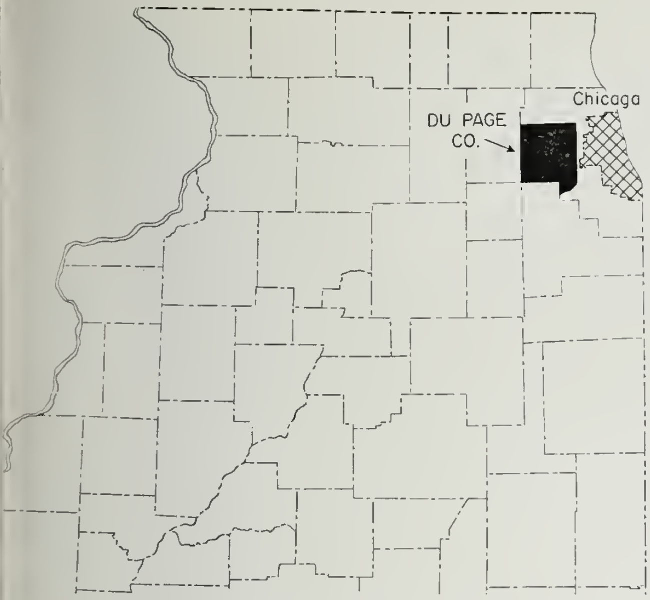


Fig. 1. Location of DuPage County.

ounty was in farms; however, expansion in suburban velopment from the city of Chicago has resulted in pid municipal and industrial growth. The principal mmunities are along the east-west lines of the Chicago d Northwestern and the Chicago, Burlington, and uincy Railroads. Wheaton, with a population of about ,000, is the county seat. Argonne National Laboratory compasses about five square miles in the southeastern rt of the county.

All the communities in DuPage County obtain their ter supplies from ground water. Water required by e industries for processing and cooling and water for ral and residential use is also obtained from wells.

Topography and Drainage

DuPage County lies in the Great Lake and Till ains sections of the Central Lowland Province, a gla- ted lowland that extends from the Appalachian ateau on the east to the Great Plains of Kansas, braska, and the Dakotas on the west. All of the nty is in the Wheaton morainal country subdivision the Great Lake section except the southwestern part, ich is in the Bloomington ridged plain subdivision the Till Plains section (Leighton et al., 1948, p. 18). e county is characterized by low, broad, glacial raines with numerous swamps and undrained areas. e numerous undrained areas in the moderately dis- ted upland are characteristic of young, poorly-inte- ted drainage systems in glaciated regions. Bedrock xposed and affects surface features only locally.

The west and east branches of the DuPage River and t Creek flow generally south. The Des Plaines River the southeastern county boundary and flows southwest. The valleys of the two branches of the DuPage River and Salt Creek originated during deposition of glacial materials and have not been significantly modified since. In a few places the rivers transect high morainal ridges; for example, the West Branch of the DuPage River west of Winfield. The southern reaches of the East Branch of the DuPage River in DuPage County are above a bedrock valley that has been partially filled.

The Des Plaines River flows in a valley formed by dissection of a bedrock divide by an earlier river. The floor and the lower slopes of the valley walls are cut in bedrock. This valley was an outlet channel of glacial Lake Chicago and later carried discharge from other glacially ponded waters in the Superior, Huron, Erie, and Michigan basins (Bretz, 1955, p. 33). The natural drainage of the Des Plaines River has been altered by man by construction of the Illinois and Michigan Canal and the Chicago Sanitary and Ship Canal.

In most places, relief in the upland is less than 50 feet. Relief is greater along major valleys bordered by morainal deposits and often reaches a maximum of about 90 feet. The upland surface rises gradually toward the northwest and attains an elevation of about 830 feet near the northwest corner of the county. The lowest elevation is 585 feet in the Des Plaines River Valley, thereby giving a maximum relief of about 245 feet.

Climate

Precipitation, evapotranspiration, and temperature are the climatic factors directly related to the availability, storage, movement, and withdrawal of ground water. Temperature influences evapotranspiration and infiltration and also affects the rate and distribution of ground-water withdrawal.

The climate of DuPage County is a humid continental type with cold, moderately dry winters and warm to hot, wet summers. Some minor effects on the climate are produced by Lake Michigan, but these are generally minimal, especially in regard to the temperature. The lake does affect the weather conditions sufficiently to produce approximately 1 to 1.5 inches of the average annual precipitation of 34.2 inches that occurs in the county.

Sixty percent of the average annual precipitation occurs during the warmer half-year, April–September. About 40 percent of the average annual precipitation comes from thunderstorms and about 10 percent is derived from snowfall. Normally June is the wettest month and February the driest month. The average annual and monthly precipitation values for DuPage County are shown in table 1. Observations of water levels in DuPage County indicate that, in general, recharge from precipitation to the ground-water reservoir

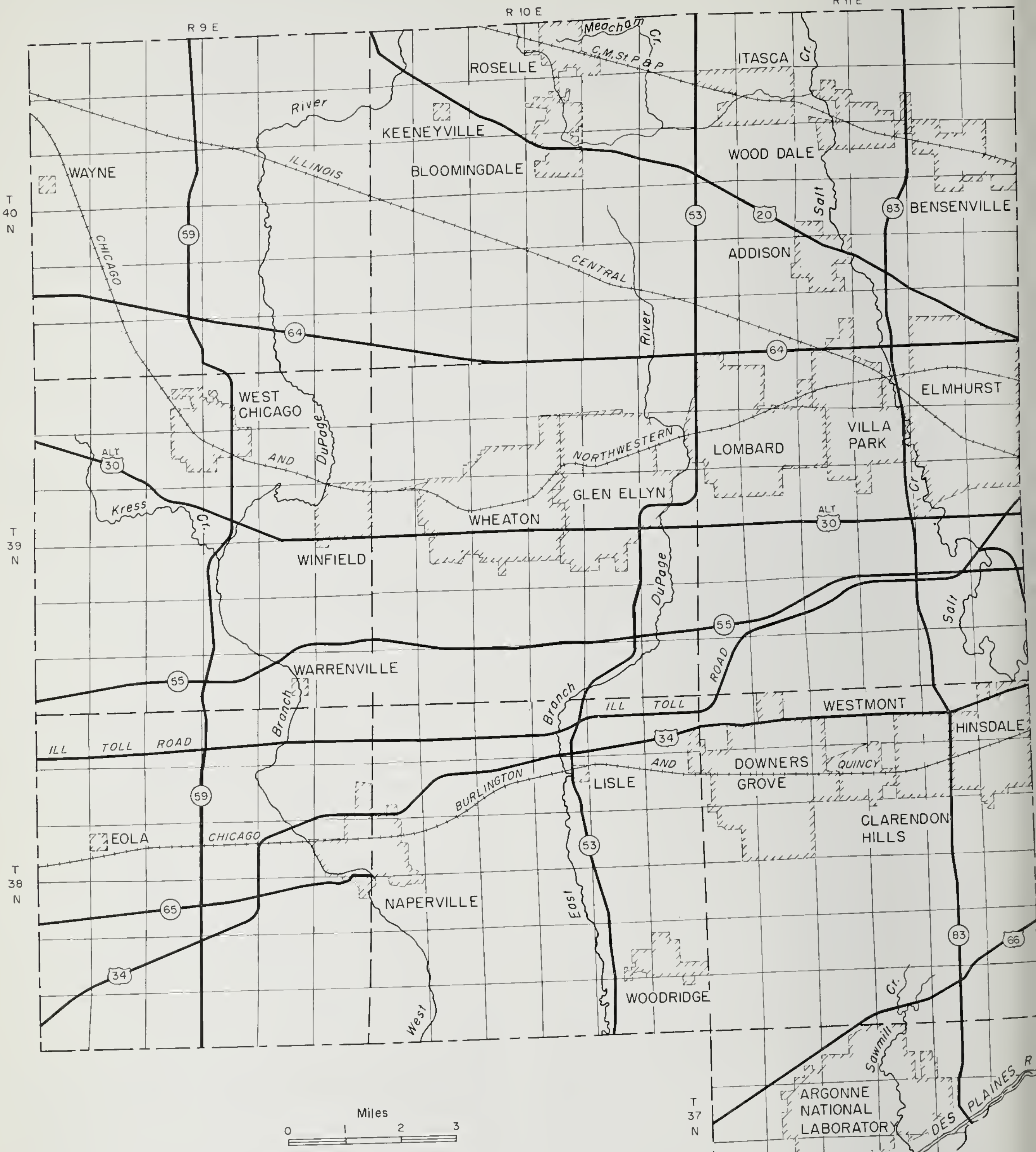


Fig. 2. Principal geographic features of DuPage County.

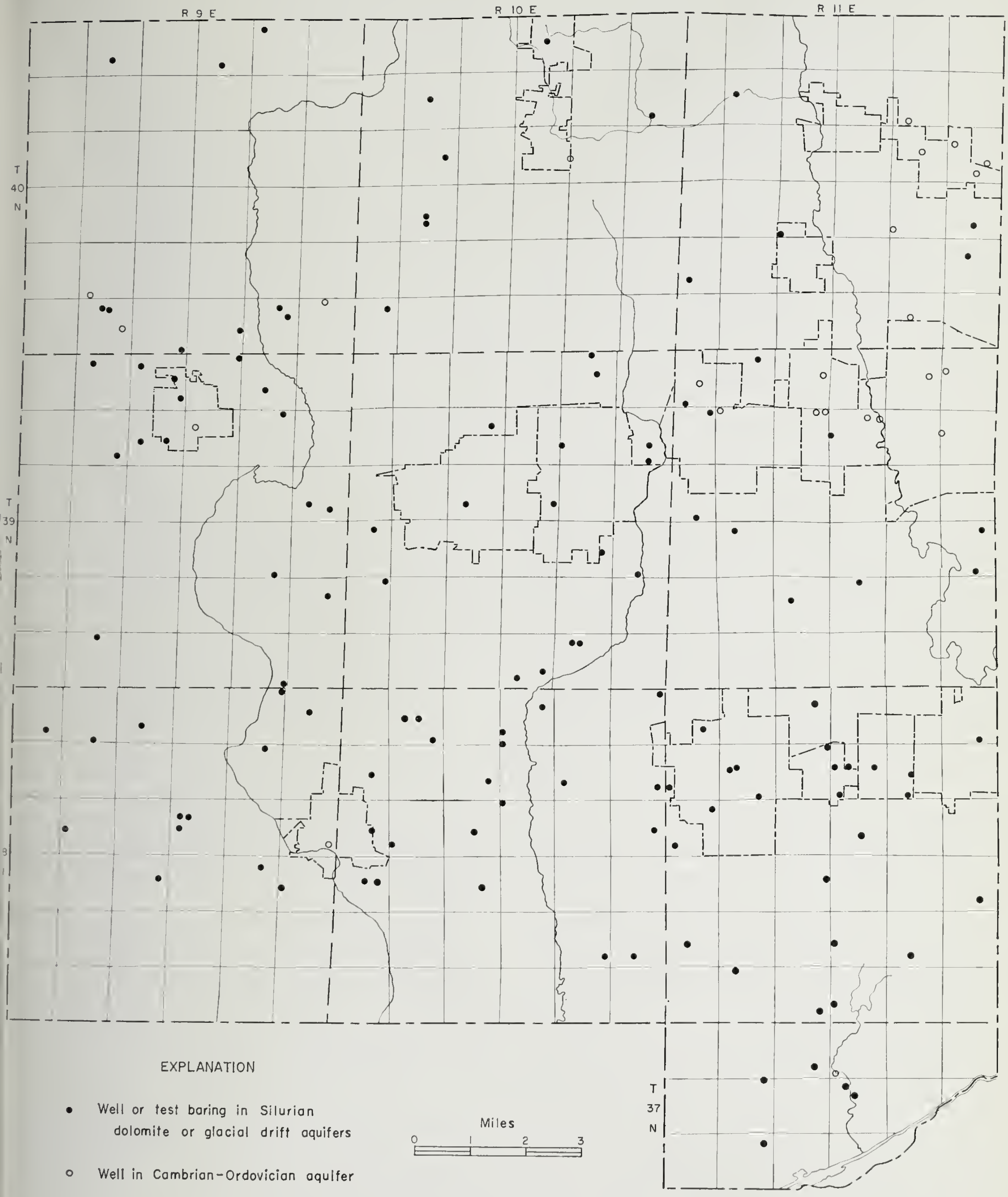

R 9 E
R 10 E
R 11 E
T 40 N
T 39 N
T 37 N
EXPLANATION
● Well or test boring in Silurian dolomite or glacial drift aquifers
○ Well in Cambrian-Ordovician aquifer
Miles
0
1
2
3

Fig. 3. Location of selected wells and test borings.

Table 1. Monthly and Annual Climatic Data (based on 1936–1960 period)

Month	Mean temperature (°F)	Average precipitation (*in*)	Greatest precipitation		Least precipitation		Average snowfall (*in*)
			amount (*in*)	year	amount (*in*)	year	
January	25.0	1.8	5.55	1960	0.29	1956	7.9
February	26.1	1.7	3.22	1957	0.14	1952	6.2
March	36.2	2.9	7.23	1948	0.38	1958	5.0
April	48.2	3.3	9.42	1946	0.93	1942	1.4
May	59.2	3.8	6.97	1945	1.09	1950	0.1
June	69.3	4.6	10.65	1939	1.10	1956	0
July	74.0	3.2	8.00	1957	0.11	1946	0
August	72.3	3.1	6.38	1937	0.55	1953	0
September	64.1	3.0	10.27	1936	0.26	1940	T
October	53.2	2.8	10.87	1954	0.18	1952	0.1
November	38.5	2.1	3.56	1945	0.60	1939	3.6
December	27.3	1.9	4.32	1936	T	1943	7.9
Annual	49.6	34.2	45.58	1954	23.44	1956	32.2

is greatest in the spring, that is, after the ground thaws and before vigorous plant growth begins.

On the average, 120 days per year have measurable precipitation. Daily precipitation equaling or exceeding 0.25 inch can be expected on 40 days per year on the average. The average monthly and annual snowfall values for the county are shown in table 1. In December and January, the months of greatest average snowfall, approximately 45 percent of the average monthly precipitation is derived from snowfall.

The length of the growing season also influences recharge because plants intercept most of the water soaking into the soil zone during this period. The growing season for the Chicago region ranges from 160 to 170 days. Dates of beginning and end of the growing season (the period between killing frosts) most commonly occur in late April or early May and in October, respectively.

As shown in table 1 there is a wide variation in mean temperature throughout the year. July on the average is the warmest month and January normally is the coldest month. There are no significant variations in the mean monthly and annual temperatures within the county. On the average, 90 days per year have daily mean temperatures below freezing. Temperatures equal to or greater than 90 degrees occur 25 days per year on the average. During the period of frequent and persistent daily temperatures below freezing, little or no recharge to the ground-water reservoir occurs because the ground is frozen and relatively impermeable.

POPULATION

Figures released by the U. S. Bureau of the Census show that during the interval 1950 to 1960 the population of DuPage County increased from 154,599 to 313,459. These figures represent a gain of 102.8 percent and a rate of increase of 15,886 persons per year. This rate of population growth shows a marked increas when contrasted to the 5,112 persons per year rate o increase during the previous 10 years (fig. 4).

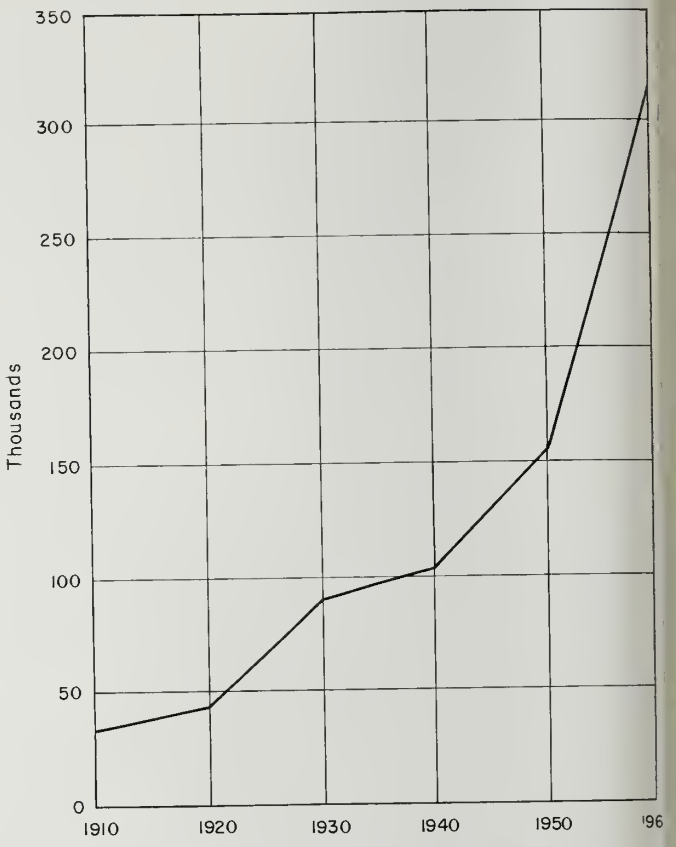


Fig. 4. Growth of population in DuPage County.

As would be expected because of the proximity o DuPage County to the city of Chicago, urban popula tion during 1950 to 1960 increased considerably ove rural population (127.9 versus 22.7 percent), and toda 85.5 percent of the total population of the county i in urban areas.

Demand for water supplies and pumpage rates closel follow these trends (compare figs. 4 and 27), and th distribution of the population in the county influence ground-water use. Thus, urban development results i areas of concentrated pumpage. The population of th townships in DuPage County is given in table 2.

ECONOMY

The quantity and quality of the ground-water sup plies of DuPage County have been, up to the present adequate to meet the demands of what was formerl largely an agricultural economy.

Favorable soil, topography, annual rainfall, temper ature range, and length of growing season have resulte in the production of a wide variety of crops. Crop

Table 2. Population of DuPage County by Township

Township	Population		
	1940	1950	1960
Addison	9,905	17,778	41,808
Bloomingdale	2,480	3,867	14,924
Downers Grove	25,607	36,264	66,664
Lisle	7,756	11,237	20,982
Milton	16,824	25,604	51,361
Naperville	3,616	4,861	8,218
Wayne	1,274	2,065	3,077
Winfield	6,857	9,561	16,437
York	29,161	43,362	89,988
Total	103,480	154,599	313,459

rown are chiefly feed crops for the dairy and livestock arms. The metropolitan area of Chicago creates the emand for dairy products, fresh vegetables, flowers, lants, and eggs.

A shift in the economy from agriculture to manufacuring has been taking place as the suburban areas row. This shift is evident by comparison of the statisics available from the U. S. Census of Manufacturers 1954, 1958) and the U. S. Census of Agriculture (1950, 959).

The number of farms and the percentage of the land n farms have decreased rapidly since 1950. The 776 rms in 1959 represent a decrease of 54 percent. In is nine-year period, the percentage of land in farms as decreased 12.3 percent to 48.3 percent. Elimination nd incorporation of the smaller, marginal farms is own by the increase in the average size of farms 131.0 acres in 1959 versus 90.0 in 1950). Dairy farms predominate in DuPage County and in 1950 they made up about 18 percent of the farms. Livestock and cash grain farms ranked second and third. Farm water supplies are obtained from ground water. Only five acres were irrigated in 1959 in contrast to 63 acres in 1950.

The number of business establishments increased by 38 percent (226 to 312) in the four-year period from 1954 to 1958. During this time the number of employees increased 41 percent to 7809 with the total payroll ($36,880,000) representing an increase in payroll of $14,644,000. Of the 16 major manufacturing groups in the county in 1954, the food and kindred products group ranked first followed closely by fabricated metal products and machinery, except electrical. The estimated amount ($70,920,000) added to the county's economy by manufacturers in 1958 was a $24,393,000 gain over the 1954 value.

Mineral production in DuPage County includes sand, gravel, and stone. Numerous sand and gravel pits are operated throughout the county, and these materials find great use in highway construction as well as in general building construction. The two largest sand and gravel plants are operated by the Elmhurst-Chicago Stone Company at Warrenville and at Barbers Corners, a few miles south of Woodridge. The only active rock quarry in DuPage County is operated by the Elmhurst-Chicago Stone Company in Elmhurst. This is one of the major quarries in the Chicago metropolitan area. Its crushed rock is used extensively as a sub-base for road and highway construction, as ballast for railroad track systems, and as a source of agricultural limestone.

GEOLOGY

General Relations

The rocks of Paleozoic age in DuPage County rest nconformably on the basement rocks of Precambrian e. The general sequence, lithologic character, waterelding properties, structure, and distribution of these cks are shown in the stratigraphic column (fig. 5), oss section of the bedrock (fig. 6), and the areal geogic map of the bedrock surface (fig. 7). The Paleozoic drock consists of about 3500 feet of consolidated, ratified, sedimentary rocks of Cambrian, Ordovician, d Silurian age. The summary of the sample study of deep well (DUP 40N11E-13.5b; Appendix B) illusates the character of the bedrock formations. These rmations dip gradually to the east and southeast at out 10 feet per mile and have been folded into a series gentle anticlines and synclines.

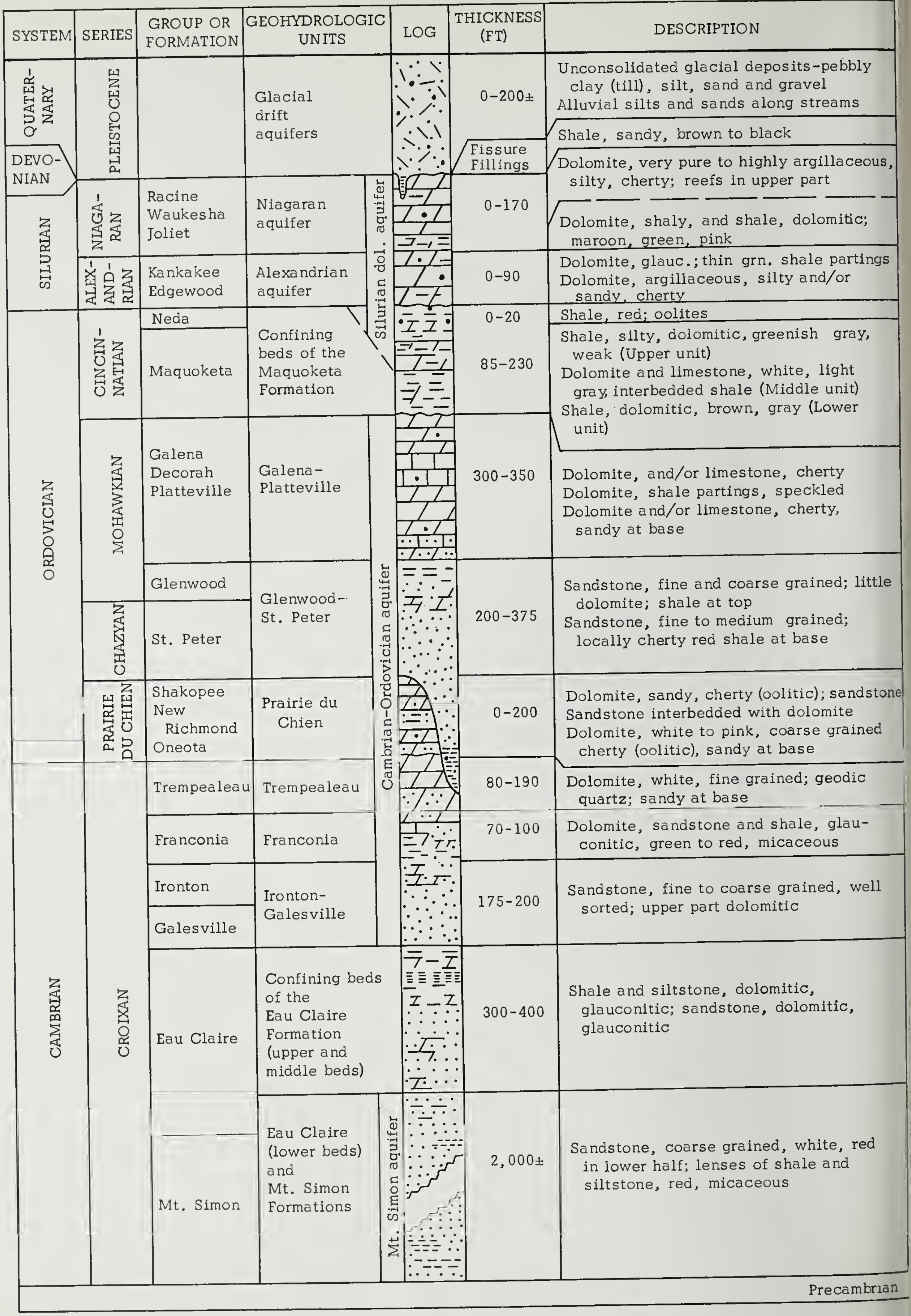
Almost all of the bedrock immediately beneath the acial drift belongs to the Silurian System (fig. 7) and part of the Niagara Cuesta which extends northward ound Lakes Michigan and Huron, and then eastward through New York state. Between the bedrock and the overlying glacial deposits is a major unconformity marked by a well-developed drainage system eroded into the bedrock surface (pl. 1).

During the Pleistocene Epoch, DuPage County was overrun by several advances of continental glaciers which, upon recession, left unconsolidated deposits that almost completely cover the bedrock (fig. 8) and reach a maximum thickness of slightly more than 200 feet (fig. 9).

Bedrock Stratigraphy

Precambrian

No wells are known to reach Precambrian rocks in DuPage County. The information obtained from wells in the surrounding area and from estimates of thickness of the Mt. Simon Sandstone suggests that these rocks are granite and related crystallines and would be encountered in drilling at depths ranging from 3000 to 4000 feet.



SYSTEM	SERIES	GROUP OR FORMATION	GEOHYDROLOGIC UNITS	LOG	THICKNESS (FT)	DESCRIPTION
QUATERNARY	PLEISTOCENE		Glacial drift aquifers		0-200±	Unconsolidated glacial deposits-pebbly clay (till), silt, sand and gravel Alluvial silts and sands along streams
DEVONIAN					Fissure Fillings	Shale, sandy, brown to black
SILURIAN	NIAGARAN	Racine Waukesha Joliet	Niagaran aquifer Silurian dol. aquifer		0-170	Dolomite, very pure to highly argillaceous, silty, cherty; reefs in upper part Dolomite, shaly, and shale, dolomitic; maroon, green, pink
	ALEXANDRIAN	Kankakee Edgewood	Alexandrian aquifer		0-90	Dolomite, glauc.; thin grn. shale partings Dolomite, argillaceous, silty and/or sandy, cherty
ORDOVICIAN	CINCINNATIAN	Neda	Confining beds of the Maquoketa Formation		0-20	Shale, red; oolites
		Maquoketa			85-230	Shale, silty, dolomitic, greenish gray, weak (Upper unit) Dolomite and limestone, white, light gray, interbedded shale (Middle unit) Shale, dolomitic, brown, gray (Lower unit)
	MOHAWKIAN	Galena Decorah Platteville	Galena-Platteville Cambrian-Ordovician aquifer		300-350	Dolomite, and/or limestone, cherty Dolomite, shale partings, speckled Dolomite and/or limestone, cherty, sandy at base
		Glenwood	Glenwood-St. Peter		200-375	Sandstone, fine and coarse grained; little dolomite; shale at top Sandstone, fine to medium grained; locally cherty red shale at base
	CHAZYAN	St. Peter				
	PRAIRIE DU CHIEN	Shakopee New Richmond Oneota	Prairie du Chien		0-200	Dolomite, sandy, cherty (oolitic); sandstone Sandstone interbedded with dolomite Dolomite, white to pink, coarse grained cherty (oolitic), sandy at base
CAMBRIAN	CROIXAN	Trempealeau	Trempealeau		80-190	Dolomite, white, fine grained; geodic quartz; sandy at base
		Franconia	Franconia		70-100	Dolomite, sandstone and shale, glauconitic, green to red, micaceous
		Ironton	Ironton-Galesville		175-200	Sandstone, fine to coarse grained, well sorted; upper part dolomitic
		Galesville				
		Eau Claire	Confining beds of the Eau Claire Formation (upper and middle beds)		300-400	Shale and siltstone, dolomitic, glauconitic; sandstone, dolomitic, glauconitic
		Mt. Simon	Eau Claire (lower beds) and Mt. Simon Formations Mt. Simon aquifer		2,000±	Sandstone, coarse grained, white, red in lower half; lenses of shale and siltstone, red, micaceous
						Precambrian

Fig. 5. Stratigraphic section, geohydrologic units, water-yielding properties of the rocks, and

DRILLING AND CASING CONDITIONS	WATER YIELDING PROPERTIES	CHEMICAL QUALITY OF WATER	WATER TEMPERATURE
Boulders, heaving sand locally; sand and gravel wells usually require screens and development; casing required in wells into bedrock	Sand and gravel, permeable Some wells yield more than 1000 gpm; specific capacities range from 1.0 to 40.7 gpm/ft, av. 13.8 gpm/ft	Hardness from 387 to 596 ppm, av. 485	46° min. 52° av. 54° max.
Upper part usually weathered and broken; extent of crevicing varies widely Chert layers slow drilling rate	Niagaran aquifer more productive than Alexandrian aquifer Basal units of Niagaran aquifer locally may retard recharge Specific capacities from 0.5 to 530 gpm/ft Coefficient of transmissibility averages 114,000 gpm/ft	Variable hardness < 200 to >1000 ppm Iron > 0.5 ppm in 60% of analyses	49° min. 52° av. 59° max.
Shale requires casing Dolomite units creviced			
Top of Galena usually selected for hole reduction and seating of casing	Development and yields of crevices are small	Regionally hardness < 100 ppm H_2S often present High alkalinity > 350 ppm	54° to 55°
Lower cherty shales cave and usually are cased Friable sand may slough	Small to moderate quantities of water Coefficient of transmissibility probably about 15% of that of Cambrian-Ordovician aquifer	Water similar in quality or slightly harder than that in Ironton-Galesville Sandstone	53° to 56°
Crevices encountered locally in the dolomite, especially in Trempealeau Casing not required	Crevices in dolomite and sandstone generally yield small to moderate quantities of water; Trempealeau locally well creviced and partly responsible for exceptionally high yields of several deep wells Coefficient of transmissibility probably averages about 30% of that of total Cambrian-Ordovician aquifer		
Amount of cementation variable Lower parts more friable Sometimes sloughs	Most productive unit of Cambrian-Ordovician aquifer Coefficient of transmissibility probably averages about 50% of that of total Cambrian-Ordovician aquifer	Iron usually < 0.4 ppm Hardness av. 200 ppm	55° to 58°
Casing usually not necessary; locally weak shales may require casing	Shales, generally not water-yielding; act as a confining bed between Ironton-Galesville and Mt. Simon		
asing not required	Moderate amounts of water; permeability between that of Glenwood-St. Peter and Ironton-Galesville	Hardness from 247 to 544 ppm, av. 352 Chlorides increase at rate of 400 ppm each additional 25' depth below elevation -1275'	66° at elev. -1300', increasing 1° with each additional 100' depth
rystalline rocks			

acter of ground water (modified for DuPage County from figure 17, Suter et al., 1959).

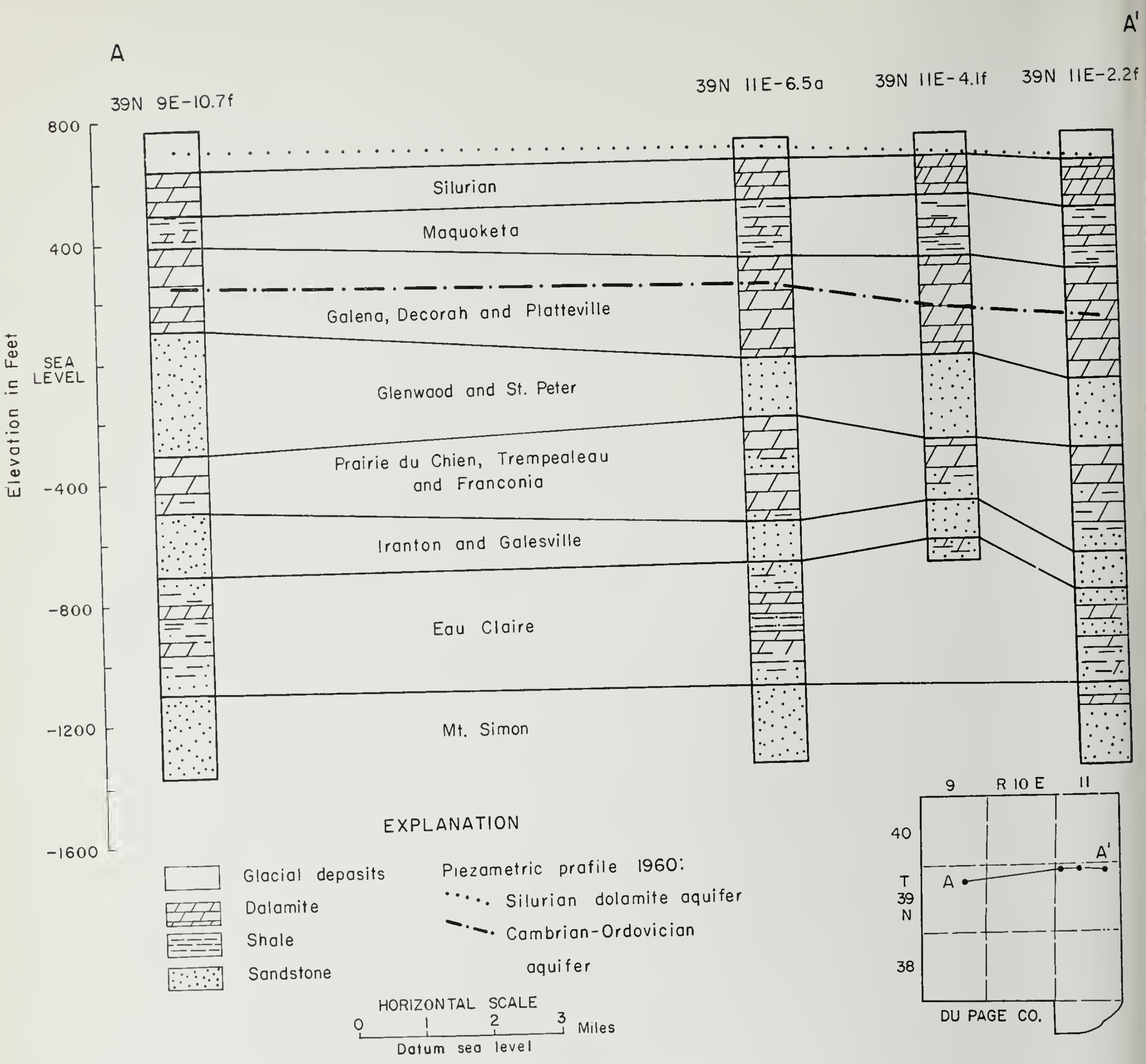


Fig. 6. Cross section of the bedrock with piezometric profiles added.

Cambrian

Rocks of Cambrian age consist chiefly of sandstone with some shale and dolomite and are known to reach a maximum thickness of approximately 2500 feet in some parts of northeastern Illinois. Most of the shale and dolomite formations occur in the upper 800 feet. No wells penetrate the entire thickness of rocks of Cambrian age in DuPage County.

The following rock units comprise the Cambrian section, from the bottom up: Mt. Simon Sandstone, Eau Claire Formation, Galesville Sandstone, Ironton Sandstone, Franconia Formation, and the Trempealeau Dolomite.

The Mt. Simon Sandstone is a pink, yellow, and white, fine- to coarse-grained, incoherent to friable sandston Locally it is arkosic and contains red and green sha beds near the base. Lenses of shale and siltstone occ at some places. The deepest water well on record DuPage County, the Chicago, Milwaukee, St. Paul, a Pacific Railroad Well No. 1 (DUP 40N11E-13.3c) w drilled to a total depth of 2290 feet and penetrated 4 feet into the Mt. Simon Sandstone. Records are ava able of 11 wells in DuPage County that enter the M Simon Sandstone but do not penetrate it completely.

Twenty-four of the wells for which records are ava able penetrate the Eau Claire Formation in DuPa County, including the 11 wells that enter the unde lying Mt. Simon Sandstone. The 13 wells which e

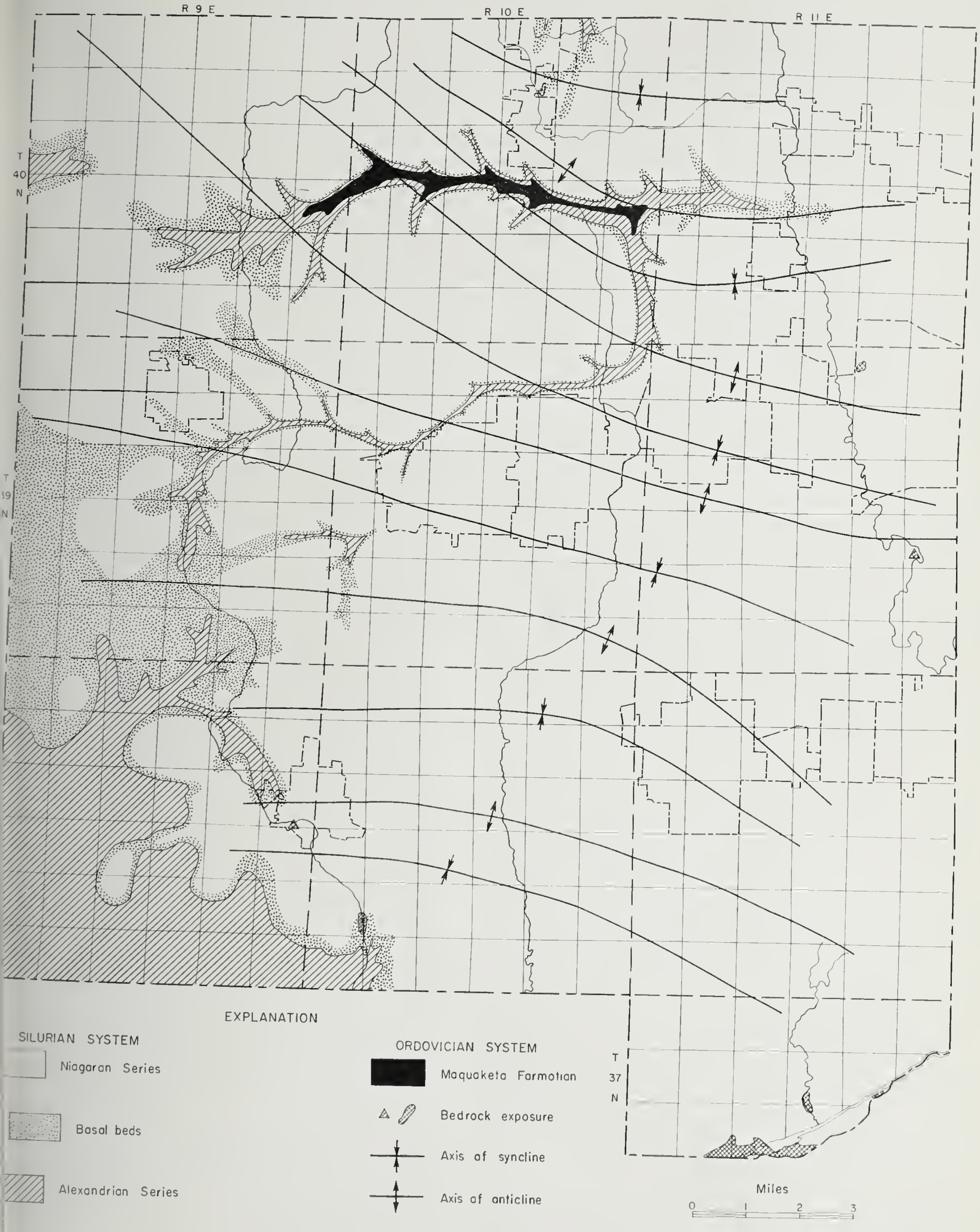


Fig. 7. Areal geology of the bedrock surface.

in the Eau Claire Formation penetrate from 4 to 54 feet. The lower sandstone of the Eau Claire Formation is incoherent, dolomitic, and contains glauconite. The middle and upper parts of the Eau Claire Formation consist chiefly of green to gray shale, dolomitic sandstone, and sandy brown dolomite. The thickness of the middle and upper parts of the formation (Suter et al., 1959, p. 19) determined from the well records, ranges from about 245 to 420 feet. Elevation of the top of the Eau Claire Formation ranges from about 550 feet below sea level along the northwestern part of the county to about 900 feet below sea level along the southeastern border. The top of the Eau Claire Formation is reached in drilling at depths of 1350 to 1500 feet.

The Galesville Sandstone consists of white to light gray, fine- to medium-grained, well sorted, incoherent sandstone that overlies the Eau Claire Formation. Strata of the Ironton Sandstone that occur immediately above the Galesville Sandstone are similar in lithology and are made up of fine- to very coarse-grained, variegated, commonly dolomitic sandstone interbedded with dolomite beds. A thin, dolomitic, coarsely glauconitic medium- to coarse-grained sandstone unit locally is present in the upper part of the Ironton Sandstone. The Ironton and Galesville Sandstones are not differentiated in most of the records of studies of drill samples from wells, and the interval is designated the Ironton-Galesville Sandstone. The combined thickness of the Ironton and Galesville Sandstones beneath DuPage County ranges from about 175 to 200 feet. The depth to the top of these sandstones ranges from about 1150 in the northwestern part of the county to about 1300 feet in the southeastern part.

The Franconia Formation is made up chiefly of interbedded sandstone, shale, and dolomite which contain an abundance of glauconite. A characteristic greenish tint often is given to sandstone and shale by the glauconite particles. The sandstone beds are pink, buff, and greenish gray, fine-grained, dolomitic, and compact. The shales are red and green, sandy, silty, and weak (cave and slake easily). Commonly the sandstone grades to sandy dolomite. Thickness of the Franconia Formation is 70 to 100 feet.

The Trempealeau Dolomite is buff to gray, very finely crystalline, and dense. Commonly the dolomite is sandy and glauconitic at or near the base of the formation. Thickness of the Trempealeau Dolomite beneath DuPage County is 80 to 190 feet. The erosional unconformity which separates the Cambrian and Ordovician rocks occurs at the top of the Trempealeau Dolomite.

ORDOVICIAN

Rocks of Ordovician age in DuPage County consist of, from the bottom up, the Prairie du Chien Series, the St. Peter Sandstone, the Glenwood Formation, t Platteville, Decorah, and Galena Formations, the M quoketa Formation, and the Neda Formation. T Prairie du Chien Series is made up of three formation the Oneota Dolomite, the New Richmond Sandstone, a the Shakopee Dolomite. This series consists almc completely of white to light gray to pink, fine to coarse crystalline, cherty (oolitic) dolomite with lenses sandstone. Beneath DuPage County, these rocks th northward from about 200 feet to a featheredge.

The St. Peter Sandstone is a white to light gray a buff, fine- to coarse-grained, locally silty and argillaceo friable sandstone. A large percentage of the quar grains is well rounded and frosted. A basal zone th has rapid changes in lithology and thickness occu where the St. Peter Sandstone is exceptionally thic This basal section may consist of fine- to coarse-graine pink to reddish brown sandstone with varying amoun of shale, chert, and dolomite fragments. The shale commonly red or green, sandy, and weak.

Thickness maps of the St. Peter and overlying Gle wood Sandstones suggest that in places the sandston were deposited in channels. In these areas, thickness of greater than 400 feet can be found. The Glenwo Formation has been recognized in many of the we in DuPage County and is a fine- and coarse-grain sandstone which contains lenses of dolomite and sha The dolomite is light gray, buff, and green and argillaceous, silty, or sandy. The shale lenses are gre and sandy, and range from plastic to tough. Thickn of the Glenwood Formation ranges from 3 to 80 f and averages 31 feet. The top of the Glenwood reached in drilling at depths of about 700 to 750 fe

The Platteville, Decorah, and Galena Formations a similar in lithology and are made up of dolomite a limestone beds. The Platteville Dolomite is common argillaceous, cherty in the upper half, buff to gray, ve fine to finely crystalline, and mottled. Near the conta with the underlying Glenwood Sandstone the dolom of the Platteville Formation is sandy. The Decor Formation overlies the Platteville Dolomite and is fine to medium crystalline, speckled (red and blac dolomite with thin gray to red shale partings. T Galena Dolomite is a fine to medium crystalline, b to brown dolomite, cherty in the lower half, and inclu scattered thin shale beds. The combined thickness these dolomites is very uniform and ranges from ab 300 to 350 feet.

The Maquoketa Formation is made up chiefly of olive gray to brown, weak, silty, dolomitic shale wh contains beds of light gray to brown dolomite. northeastern Illinois, three units have been recogni in the Maquoketa Formation (Suter et al., 1959, p. 3 From bottom to top the units are:

Lower Unit—Shale, silty, brown to very dark gray-brown, weak to brittle. Depauperate zone sometimes occurs which contains small phosphatic fossils. Thickness is about 50 to 100 feet.

Middle Unit—Dolomite, some shale and limestone, light gray to light brownish gray, a few pink and green grains, fine to coarsely crystalline, fossil fragments common. Thickness ranges from less than 50 feet in eastern DuPage County to 50 to 100 feet in the western part.

Upper Unit—Shale, dolomitic, silty, olive gray, greenish gray, weak. Some dolomite, silty, light gray to dark green, contains black speckled chert. Some fossil fragments (chiefly Bryozoa). Generally 50 to 100 feet thick.

The character of the Maquoketa Formation is shown the sample study log of the deep well DUP 40N11E-.5b (Appendix B).

The base of the Maquoketa Formation is well marked a change from shale to the buff-colored dolomite the Galena Formation. Delineation of the upper sional surface is sometimes difficult where the upper ata of the Maquoketa contain dolomite and are over- n by lithologically similar strata in the lower part the Edgewood Formation. The upper surface is easily tinguished where the Kankakee or Edgewood Dolo- tes overlie the shales of the Maquoketa Formation or ere the Neda Formation occurs. Much of the lower t of the rocks of Silurian age consists of white to nt brown, cherty, and glauconitic dolomite which trasts markedly with the darker color, black speck- , and the presence of black-speckled chert in the omite of the Maquoketa Formation.

he Neda Formation consists of a shale which is omitic, silty, hematitic, red (sometimes a green, yel- , and purple mixture), and contains goethite oolites. y, argillaceous, pink and green dolomite is often sent. The pre-Silurian erosion has resulted in very chy occurrence of the Neda Formation in DuPage nty, and where this formation occurs the entire uoketa section is present. Only 10 of the 74 wells lied penetrated the Neda Formation. Commonly, re the Neda Formation occurs, the overlying Edge- d Formation of the Alexandrian Series is thin. ally, Kankakee Dolomite lies directly upon the Neda mation. The boundary between rocks of Ordovician Silurian age is easily determined where the colorful e of the Neda Formation is overlain by the dolomite he Alexandrian Series. The thickness of the Neda nation, where present, ranges from 5 to 15 feet.

RIAN

ocks of Silurian age in DuPage County include the andrian Series overlain by the Niagaran Series. e rocks form essentially all of the bedrock surface ath the glacial drift and the few bedrock outcrops e county (fig. 7).

Alexandrian Series

The Alexandrian Series is composed chiefly of dolomite which decreases in clastic content from the base of the series upward. Shale and very argillaceous dolomite beds occur near the base of the series and grade to a relatively pure dolomite near the top.

Erosional thinning of the Alexandrian Series has occurred where the rocks form the surface of the bedrock. Approximate original depositional thicknesses are present throughout most of the county where these rocks are overlain by the Niagaran Series.

Two formations make up the Alexandrian Series, the Edgewood below and the Kankakee above. The Edgewood Formation is a gray to brownish gray, argillaceous, cherty dolomite which contains coarse silt and fine sand and shale partings toward the base. The Kankakee Formation is a white to light brown to light gray, relatively clean, locally glauconitic dolomite which contains thin green shale partings. It is difficult to distinguish the upper Edgewood Formation from the overlying Kankakee Formation by study of cuttings from water wells. The two formations are not differentiated for this study. The character of the Alexandrian rocks is shown in the study of reference wells DUP 38N11E-30.5d and DUP 39N11E-4.1e (Appendix B).

The lithologic changes which mark the boundary between the Alexandrian Series and the Maquoketa or Neda Formations have been described. The contact between the Alexandrian and Niagaran Series is a smooth bedding surface which can be seen in the Elmhurst quarry and in outcrops along the Des Plaines and Kankakee Valleys in Will County. In DuPage County, the basal beds of the Niagaran Series are red, green, and greenish gray, shaly dolomite and shale. The abrupt change in color and lithologic character between these beds and the Kankakee Dolomite of the Alexandrian Series is easily discernible.

Niagaran Series

The rocks of the Niagaran Series have been subdivided into the Joliet, Waukesha, and Racine Formations. These formations range from clean dolomite to highly silty, argillaceous, and cherty dolomite with some thin shale beds, and contain reefs locally. Reefs and associated strata are most characteristic of the Racine Formation but may occur stratigraphically as low as the Joliet Formation (Willman, 1949, p. 26).

Regionally, these formations have been defined in outcrop chiefly on differences in the lithologic character of the dolomite. The formations are conformable and have contacts that are transitional between clean carbonates and very silty and argillaceous carbonates. For this report, these lithologically similar formations were not differentiated by study of drill samples from wells because of the transitional nature of the contacts and because of the presence of reef and reef-like deposits.

The lower beds of the Joliet Formation, however, are characterized by their pink or red color and distinctive lithology and are easily recognizable in samples of drill cuttings.

A zone of dolomitic shale about 12 inches thick differentiates these basal beds of the Niagaran Series into three distinct units. From bottom to top, these units are: a shaly dolomite, a dolomitic shale, and a shaly silty dolomite. The presence of the middle shale is usually difficult to determine by study of well cuttings because it tends to be washed away during drilling. The character of these beds is shown in the sample study log of the Villa Park City Well No. 7 (DUP 39N11E-4.1e; Appendix B).

The red shaly dolomite of the basal beds of the Niagaran Series contrasts markedly with the underlying light brown to light gray, relatively clean dolomite of the Kankakee Formation, and the contact between the Niagaran and the underlying Alexandrian Series is easily distinguished in surface and subsurface studies.

Erosion has been active upon the upper surface of the rocks of Niagaran Series and considerable thinning has resulted, particularly where deep valleys have been carved into the dolomite bedrock. This erosional thinning prevents accurate determination of the original thickness of the Niagaran Series in DuPage County. The upper eroded surface of the dolomite of the Niagaran Series is highly creviced. Black shale has been found in crevices in the dolomite of the Niagaran Series in the Elmhurst quarry and locally throughout the region. Fossils in this material are middle and late Devonian in age (Alden, 1902, p. 93–94). Unconsolidated glacial materials of Pleistocene age overlie the dolomite of Niagaran age in most of the county.

Bedrock Structure

DuPage County is on the northeastern flank of the Kankakee Arch, an asymmetrical anticline which trends about S 40°E and plunges to the southeast (Willman and Payne, 1942, p. 184). The Kankakee Arch connects the Cincinnati and Wisconsin Arches and separates the Michigan and Illinois basins. The bedrock formations in DuPage County dip to the east and southeast at about 10 feet per mile. Gentle folds are well defined by all stratigraphic horizons and pitch with the dip. The axes of these folds in the dolomite of Silurian age are shown on the areal geologic map of the bedrock surface (fig. 7).

Jointing in the dolomite of Silurian age is well exposed in quarries and, where measured, indicates two major systems of joints that trend about N 50°E and N 47°W The northeastern trend of the dolomite joints is at rigl angles to the trend of the Kankakee Arch and the secon joint trend makes an angle of about 7° with the trend o the arch.

More data are necessary before precise relationshi can be established between joint development and r gional and local structures. Table 3 lists the data co lected for this study on trends of joint systems in t dolomite of Silurian age.

Table 3. Trend of Joint Systems

1/4	1/4	1/4	Sec.	Twp.	Range	NE trend	NW trend
SW	NW	SW	16	37N	11E	N 40° E	N 63° W
SE	SW	SE	13	38N	9E	N 43° E	N 56° W
SE	NW	NE	30	38N	10E	N 60° E	N 35° W
S	SW	NW	2	39N	11E	N 54° E	N 44° W
SW	NW	SE	17	39N	12E	N 60° E	N 36° W
NW	SE	NE	17	39N	12E	N 48° E	N 38° W
NE	NW	SE	17	39N	12E	N 48° E	N 57° W
Average						N 50° E	N 47° W

History of the Bedrock

Numerous transgressions and regressions of shallo seas across northeastern Illinois are recorded by t sedimentary bedrock formations in DuPage County. gradual wearing down of the surrounding exposed ro masses by erosional processes, deposition of the sands a muds into the sea, and later consolidation formed san stone and shales. When the seas were clearer, the ca bonate from which the limestone and dolomite rocks we formed was deposited. The periods of sediment depo tion and consolidation were interrupted by episodes uplift and deformation during which the exposed roc underwent weathering and erosion. Perhaps the maj period of uplift and erosion occurred after the depositi of the rocks of Prairie du Chien age. This uplift sulted in the formation of the Kankakee Arch (Ekbla 1938, p. 1428). The erosion during this major uplift w extensive and rocks as deep as the Franconia Formati were cut into and removed. It was on this irregular s face that the St. Peter Sandstone was deposited and major unconformity within the bedrock sequence w formed.

Conditions of deposition of the Maquoketa Formati favored accumulations of mud and silt with mi amounts of calcareous material. Sometime during middle of this interval the seas cleared with a decre in the amount of clastic materials and an increase the amount of the calcareous material deposited.

The shallow sea in which the Alexandrian sediments were deposited transgressed a highly uneven Maquoketa surface and reworked the upper part of the shale depositing it with the carbonate. Clastic material was concentrated in the deeper parts of the sea and particularly in channels which had been cut into the Maquoketa surface (Buschbach, 1959, p. 85). With time, the sea became deeper, cleaner, and more quiet. Clastic deposition decreased and then essentially ceased.

Environmental conditions during the time of the deposition of the Joliet and Waukesha Formations of the Niagaran Series fluctuated from those which cause continuous deposition of relatively clean carbonates to those which cause deposition of very silty and argillaceous carbonates. The recognition of individual units in the Joliet Formation from outcrop to outcrop throughout most of the region and the great similarity of insoluble residues of these units show widespread uniformity of lepositional conditions (Workman, 1949). In contrast, luring the time of deposition of the Racine Formation, eef building was more widespread and caused highly ariable and complex sedimentation conditions locally.

Unknown thicknesses of sediments were deposited on he dolomite of Silurian age in shallow, continental seas vhich invaded the county during Devonian and perhaps ven Mississippian and Pennsylvanian times. Major eriods of structural disturbance which formed the genle folds in the bedrock and emergence of the land took lace in late Silurian time and near the end of the Iississippian period (Willman and Payne, 1942, p. 195). he sediments which were deposited on the dolomite of ilurian age may have been removed during the late-Iississippian-pre-Pennsylvanian erosional interval or uring the long period of time between the Pennsylanian and the Pleistocene. The only evidence of transression of the seas over the county after Silurian time limited to the small quantities of shale of Devonian ge found in some of the openings near the upper urface of the dolomite of Silurian age.

The geologic record of the time between the Pennsylanian and the Pleistocene in this region is poorly nown. After withdrawal of the Paleozoic seas, a long eriod of weathering and erosion produced a surface low relief upon the dolomite. Advances of the ice eets during the Pleistocene scoured the surface of e dolomite and covered it with thick deposits of nconsolidated material.

Bedrock Topography

The bedrock topography map of DuPage County l. 1) was compiled almost entirely from about 1250 cords of water wells and test borings because of the w outcrops of bedrock and the thick glacial drift cover. This map agrees in general with an earlier interpretation presented by Horberg (1950, pl. 1, sheet 1).

The bedrock surface is principally a broad, gently rolling upland, part of the Central Illinois Peneplain (Horberg, 1950, p. 95), which extends over northeastern and central Illinois. The development of the peneplain began some time after the Pennsylvanian Period and was terminated by Pleistocene glaciation.

Regionally, because of the presence of less resistant shales above and below it and because of its gentle eastward dip, the Silurian dolomite became a cuesta. The ridge of the cuesta became a major divide for drainage, so that many streams drained westward. The eastward-draining bedrock valleys trend approximately parallel to the dip of the bedrock but diverge slightly to the northeast. They have been interpreted as tributaries of a valley cut into the soft Devonian shales to the east (Horberg, 1950, p. 28).

The bedrock surface in DuPage County slopes from about 700 feet above mean sea level in the northwest to about 640 feet in the southeast and to about 580 feet in the northeast. Some small isolated hills in the bedrock surface in the eastern part of the county may reflect relatively resistant reef structures.

The valleys in the bedrock surface are generally about one-half to one mile wide and about 80 feet deep and for the most part are filled completely with glacial drift. The tributary valleys which were cut back into the rock uplands have steep slopes and are commonly narrow. Major joint systems appear to have locally influenced the trend of the valleys. Most of the valleys were created by preglacial erosion, but some are related to glacial events.

Only two present-day river valleys overlie bedrock valleys in DuPage County. The southern reaches of the East Branch of DuPage River flow in a broad lowland which partly overlies a buried bedrock valley. Where the West Branch of DuPage River leaves the county, it overlies the head of a buried bedrock valley. Des Plaines River, along the southeastern boundary of the county, flows in an outlet valley of Glacial Lake Chicago cut down to an elevation of about 585 feet above mean sea level, across the bedrock drainage divide.

Unconsolidated Deposits

Glacial Drift

Almost all unconsolidated glacial deposits in DuPage County were deposited by ice of the Lake Michigan glacial lobe of Wisconsinan age, the most recent Pleistocene glacial stage. The recent classification of the Wisconsinan stage by Frye and Willman (1960) is as follows:

STAGE	SUBSTAGE	MORPHOSTRATIGRAPHIC UNITS
Wisconsinan (glacial)	Valderan (glacial)	
	Twocreekan (ice retreatal)	
	Woodfordian (glacial)	Tinley moraine
		Valparaiso moraines
		Palatine moraine
		Roselle moraine
		Keeneyville moraine
		Minooka moraine
	Farmdalian (ice retreatal)	
	Altonian (glacial)	

A map of the surficial geology is presented in figure 8. Surficial geologic maps of parts of DuPage County have been published by Trowbridge (1912, pl. 2), Fisher 1925, pl. 1), Fryxell (1927, pl. 1), Bretz (1955, supplement to Bulletin 65), and Ekblaw (in Suter et al., 1959, fig. 5). Some of the revisions of the earlier mapping of the Wheaton Quadrangle, in progress by Block, have been included in the surficial geologic map in figure 8.

Topography

Although glacial drift materials may range widely in composition, they have characteristic land forms generally independent of the underlying bedrock surface. The most prominent and abundant land form in DuPage County is glacial moraine, an accumulation of drift deposited by the glacial ice. It is differentiated into end moraine, which is more or less an undulatory ridge-like deposit of glacial drift built along the border of a glacier; and ground moraine, which comprises areas of low relief behind the end moraine and was deposited as the glacier melted back.

Many of the end moraines in DuPage County are distinct and easily traceable topographic features and are named generally from a town built upon them. The same names are applied to the areas of ground moraine respectively associated with the end moraines.

Composition

The glacial drift in DuPage County consists almost entirely of three types of materials: till, glaciofluvial deposits, and glaciolacustrine deposits. At some places, these deposits grade into one another.

Till generally consists of a heterogeneous mixture of particles of all sizes. Till ranges from very compact (often called ''hardpan'' by drillers) to loose and friable. The heterogeneity of till results from direct deposition by glacial ice without any significant sorting action by water. The tills in DuPage County range from a dense clayey till almost completely lacking coarse fragments to a gravelly, sandy till closely associated with water-worked materials. Most of the tills of the Minooka, Valparaiso, and Tinley Moraines (fig. 8) have a high clay content and a scarcity of pebbles and coarser fragments. The study of the split-spoon samples from a test boring in the West Chicago end moraine northeast of Naperville shows the character of the clayey tills (DUP 38N10E-5.6d; Appendix B). The till which forms most of the West Chicago end moraine contains abundant quantities of sand and gravel and is closely associated with water-laid materials northwest of West Chicago. The description of some of the drill cuttings of a well near West Chicago shows the coarse-textured material which frequently occurs in this till (DUP 39N9E-3.1h; Appendix B).

A coarse-textured glacial drift occurs widely under the Valparaiso drift in southeastern DuPage County. It closely resembles the Lemont drift, which is a complex of silty till and water-laid silt, gravel, and sand occurring beneath Valparaiso drift throughout much of the upland area bordering the Des Plaines Valley (Horberg and Potter, 1955, p. 9 and 17). A study of split-spoon samples from a test boring shows the nature of occurrence and character of this coarse-textured glacial drift (DUP 39N11E-28.6e; Appendix B).

Glaciofluvial deposits consist of material deposited by glacial melt-waters and exhibit a distinct sorting of constituent particles. These deposits may range from clay to gravel and frequently show sharp changes in texture. Types of glaciofluvial deposits which occur locally on land surfaces in DuPage County are kames, kame terraces, and eskers. More widespread deposits of glaciofluvial materials are found in the form of valley-train along the major drainages and as outwash-plain bordering the West Chicago end moraine (fig. 8). Glaciofluvial deposits commonly are interbedded with till and are represented by extensive buried sheets of outwash sand and gravel. Glaciofluvial deposits frequently are lenticular, discontinuous, and erratic in nature. Where the end moraines contain large quantities of coarse-textured glaciofluvial material they have a rough, irregular topography. The prominent topographic expression of the West Chicago end moraine as compared with the others in the county reflects in part the coarseness of its composition. The nature of occurrence and character of the interbedded sands and gravels are shown in the study of split-spoon samples from a boring near the western boundary of the county (DUP 38N9E-6.2b; Appendix B).

Glaciolacustrine deposits in DuPage County consis chiefly of laminated silt and clay which were deposited in pro-glacial lakes. Coarser textured materials may have been deposited along the shorelines of the lakes Laminated silts of glaciolacustrine origin mainly ar found in the depressional areas of the Minooka groun moraine in the southwestern part of the county. Th character of these laminated silts is shown in a study of split-spoon samples (DUP 38N9E-4.5c; Appendix B)

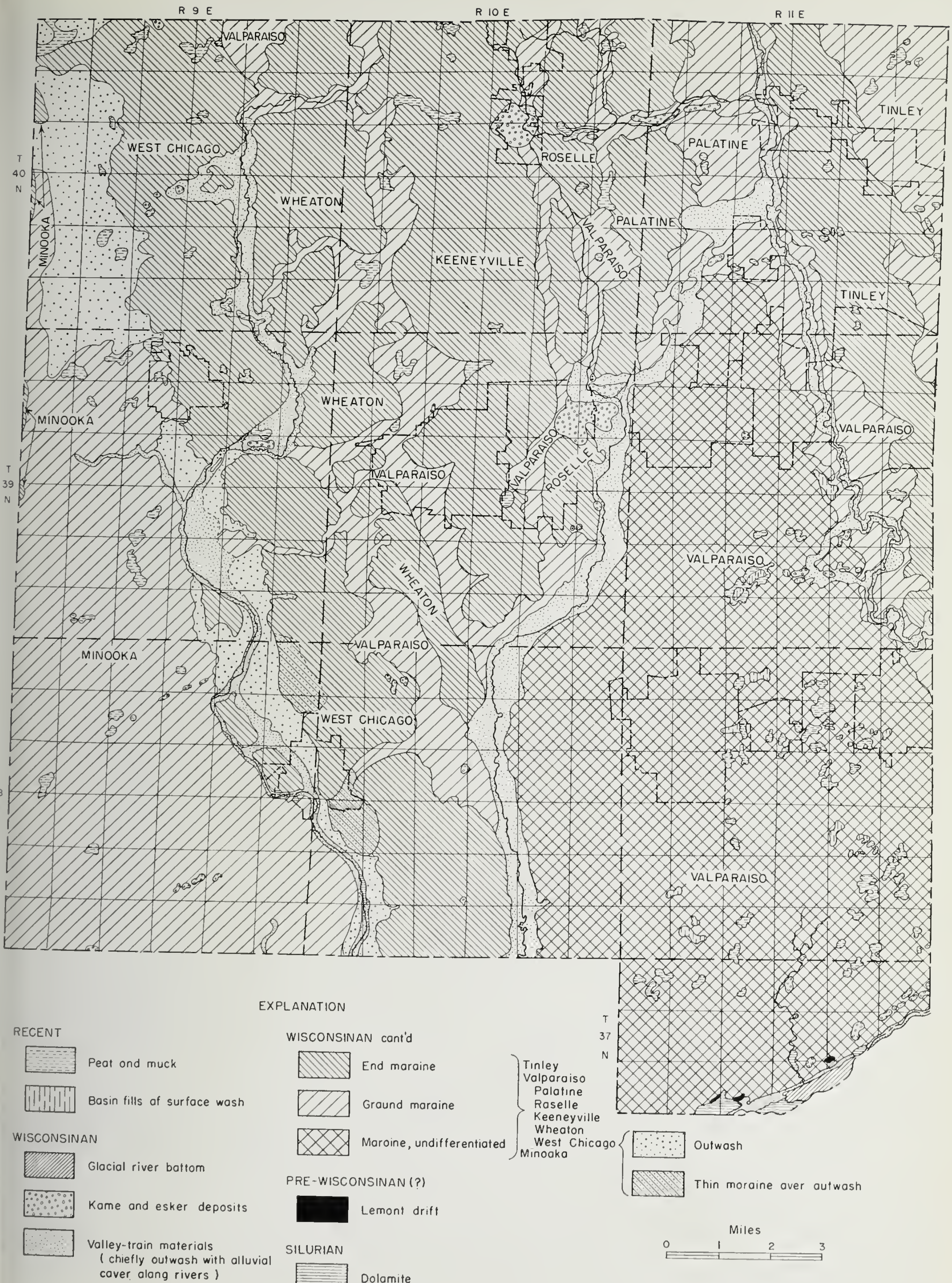


Fig. 8. Surficial geology.

RECENT DEPOSITS

Peat and muck are being formed at the present time in many of the low basins in the poorly-drained morainal areas in the county. Surface wash is depositing silts and clays in the natural depressions. The rivers and streams are reworking the glacial deposits and are forming alluvial deposits.

The soils being developed from the unconsolidated materials in DuPage County are chiefly silt loams. The soil types mapped in DuPage County (Hopkins et al., 1917) have since been grouped on the basis of parent materials and surface color and included in a colored map of *Parent Material and Surface Color of Soils in Northeastern Illinois* prepared by the University of Illinois Agricultural Experiment Station, 1957. The soils included in each group on this map occur in close geographic association over relatively wide areas, were developed in similar parent material and under a cover of similar vegetation, have approximately the same number and sequence of horizons but differ in oxidation or drainage profile, and form in general a soil catena (Wascher et al., 1960, p. 92–93).

THICKNESS

The unconsolidated deposits have a maximum thickness of slightly more than 200 feet (fig. 9). The deposits attaining a thickness generally greater than 100 feet occur in a zone extending from the north-central part of the county southward through Wheaton and Glen Ellyn and southeastward through Downers Grove and Argonne National Laboratory (figs. 9 and 2). Areas less than 50 feet thick occur for the most part in the southwestern part of the county, locally in the eastern tier of townships, and along the southern reaches of the East Branch of the DuPage River.

Areas of thicker unconsolidated deposits correspond with bedrock valleys (fig. 9 and pl. 1) and with areas of high land-surface topography formed by end moraines. Greatest thicknesses occur where end moraines lie over bedrock valleys such as in the north-central part of the county and in the vicinity of Clarendon Hills.

The unconsolidated deposits are generally thinner in the low areas between end moraines. The thinnest deposits are located where ground moraine occurs above high bedrock. This condition is common in the southwestern part of the county.

HISTORY

The surficial materials of Pleistocene age and the subsurface relationships established by study of well cuttings and drillers' logs record a complex series of glacial events in DuPage County.

Evidence of pre-Illinoian or early Illinoian glacial activity has not been found in DuPage County. As th ice withdrew behind the crest of the Niagara Cuesta i late Illinoian time, ponding and slackwater depositio took place (Horberg and Potter, 1955, p. 18). Th Lemont drift may represent the readvance of the lat Illinoian (Horberg and Potter, 1955, p. 18) or earl Wisconsinan (Frye and Willman, 1960, p. 6) ice up th backslope of the Niagara Cuesta. Horberg and Potte believe that the coarse texture of this drift represent incorporation of the water-laid deposits into the fluctu ating ice front. Exposures of Lemont drift are limite to a few scattered localities along the Des Plaine Valley (fig. 8) but Lemont drift may occur beneat the surficial drift in much of the upland area in th southeastern part of the county. Discharge of th ponded meltwater, after the retreat of the ice whic deposited the Lemont drift, cut across the bedrock d vide and formed the Des Plaines Valley (Horberg an Potter, 1955, p. 19).

All the moraines in the county are of Woodfordia age. The Minooka Moraine differs from the earlie Marseilles Moraine chiefly by a notable change in alig ment and seems to indicate a significant withdraw and readvance of the ice (Frye and Willman, 196 p. 8). Extensive deposits of outwash sands and grave associated with the retreat of the earlier Marseilles i were overridden by the Minooka and Valparaiso i north of Elgin (Suter et al., 1959, p. 39). Some these gravels may extend back beneath the Minooka ar Valparaiso tills in DuPage County. Deposits of glaciol custrine silts on Minooka ground moraine in the sout western part of the county are evidence of ponding.

Minor fluctuations of the Valparaiso ice are record by the north-south-trending end moraines which cov all but the southeastern part of the county. The clay Valparaiso tills may have been deposited as a thin cov over thick silty Lemont drift in the southeastern pa of the county (Bretz, 1955, p. 106). It is here that t well-defined north-south Valparaiso end moraines b come less distinct and apparently swing eastward. T complexity of the surface topography in this area ma result in part from the configuration of the underlyi Lemont drift (Bretz, 1955, p. 71). This complexi prevents differentiation of the Valparaiso end morain in this area.

During the building of the most prominent of t Valparaiso end moraines, the West Chicago end morain a fairly extensive outwash plain was deposited. W Chicago outwash occurs beyond the border of the W Chicago end moraine in much of the county and as valley-train along the West Branch of the DuPa River. Local overriding of this deposit by the ice shown northwest and southeast of Naperville where

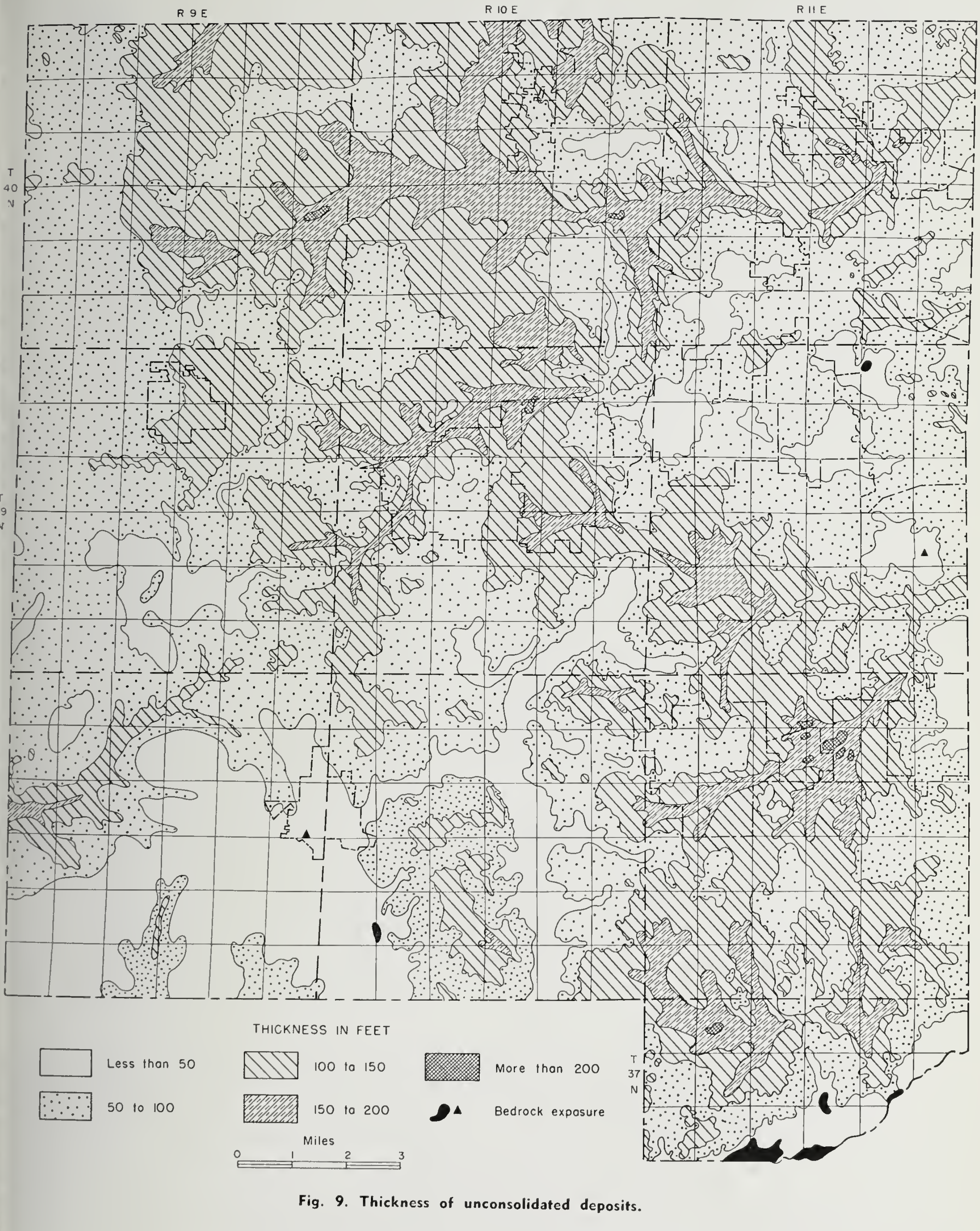


Fig. 9. Thickness of unconsolidated deposits.

thin cover of West Chicago till is found over West Chicago outwash (figs. 8 and 12 BB′).

After building the narrow end moraines and depositing considerable quantities of outwash materials along what is now the East Branch of the DuPage River, the Valparaiso ice retreated from the county. Readvance of the ice up the backslope of the Valparaiso Moraine resulted in construction of the Tinley Moraine in the northeastern corner of the county. The Tinley End moraine is relatively slender and extends as a ridge parallel to the lake basin to the east. Withdrawal of the ice from the position of the Tinley end moraine initiated Glacial Lake Chicago and ended major glacial activity in DuPage County. The Des Plaines Valley, however, from time to time continued to act as an outlet for Glacial Lake Chicago.

RELATIONSHIP OF GEOLOGY TO GROUND WATER

A large reservoir of ground water occurs in the saturated earth materials beneath the land surface in DuPage County. Variations in the lithologic character, distribution, and structure of the earth materials control the occurrence, source, movement, and availability of ground water. A sound and detailed knowledge of the geology is necessary for a basic understanding and interpretation of ground-water conditions.

Aquifers are lithologic units or combinations of such units that have an appreciably greater transmissivity than adjacent units and that store and transmit water that is recoverable in usable quantities. The aquifers in DuPage County consist of sand and gravel, sandstones, and creviced limestones and dolomites.

Geohydrologic units are geologic units which act hydraulically more or less as a distinct hydraulic system. On the basis of character and origin of the deposit, stratigraphic position, water-bearing properties, and use, six principal geohydrologic units are recognized in the earth materials beneath DuPage County. From top to bottom, these geohydrologic units are: 1) glacial drift aquifers, 2) Silurian dolomite aquifer, 3) confining beds of the Maquoketa Formation, 4) Cambrian-Ordovician aquifer, 5) confining beds of the Eau Claire Formation, and 6) the Mt. Simon aquifer. The glacial drift and Silurian dolomite aquifers are hydraulically separated from the Cambrian-Ordovician aquifer by the relatively impermeable shales of the Maquoketa Formation. The Cambrian-Ordovician aquifer is separated from the deeper Mt. Simon aquifer by the impermeable beds of the Eau Claire Formation.

Glacial Drift Aquifers

The glacial drift aquifers are the saturated, relatively clean, coarse-textured deposits of sand and gravel which occur erratically throughout the glacial drift. The clayey tills within the county are commonly too fine-grained and poorly sorted to have sufficient permeability to be considered as aquifers. The silty tills that are often closely associated with coarse-textured material may be moderately permeable. Small lenses of sand and gravel in the till provide limited quantities of water to large-diameter dug wells.

Where deposits of sand and gravel are penetrated during the drilling of a well, they generally are bypassed in favor of completion in the underlying dolomite. Traditionally, this procedure has been followed because of the relative ease of well completion and development in the dolomite and because of the common belief that rock wells are more reliable and desirable. Wells drilled in the glacial sand and gravel aquifers, particularly in areas where thick deposits are available and where the underlying Silurian dolomite aquifer is limited in its yield, may produce greater yields of ground water of better quality and lower temperature than the bedrock aquifers.

The occurrence of glacial drift aquifers is extremely irregular, and their character and distribution range widely. The geology of the unconsolidated deposits provides a basis for the general determination and delineation of these aquifers, and small diameter test holes may be drilled to locate and evaluate the glacial drift aquifers more precisely.

Three categories of glacial drift aquifers are recognized in DuPage County on the basis of their mode of occurrence: 1) surficial, 2) interbedded, and 3) basal.

Surficial glacial drift aquifers occur just below land surface and are made up chiefly of relatively coarse-grained glacial outwash deposits (sand or larger). The deposits commonly are well sorted and have wide ranges and abrupt changes in grain size laterally and vertically. The changes in texture and sorting which characterize these materials cause inconsistencies in their water-yielding properties. Permeability is often high but varies widely with the coarser-textured, clean deposits of sand and gravel having the higher permeabilities.

Surficial deposits of coarse-textured sand and gravel which appear to be sufficiently thick and extensive for development as sources of ground water occur chiefly in the outwash materials concentrated as valley-trains along the East Branch and West Branch of DuPage River and as an outwash plain in front of the West Chicago end moraine. The study of split-spoon samples from a test hole along the East Branch of DuPage

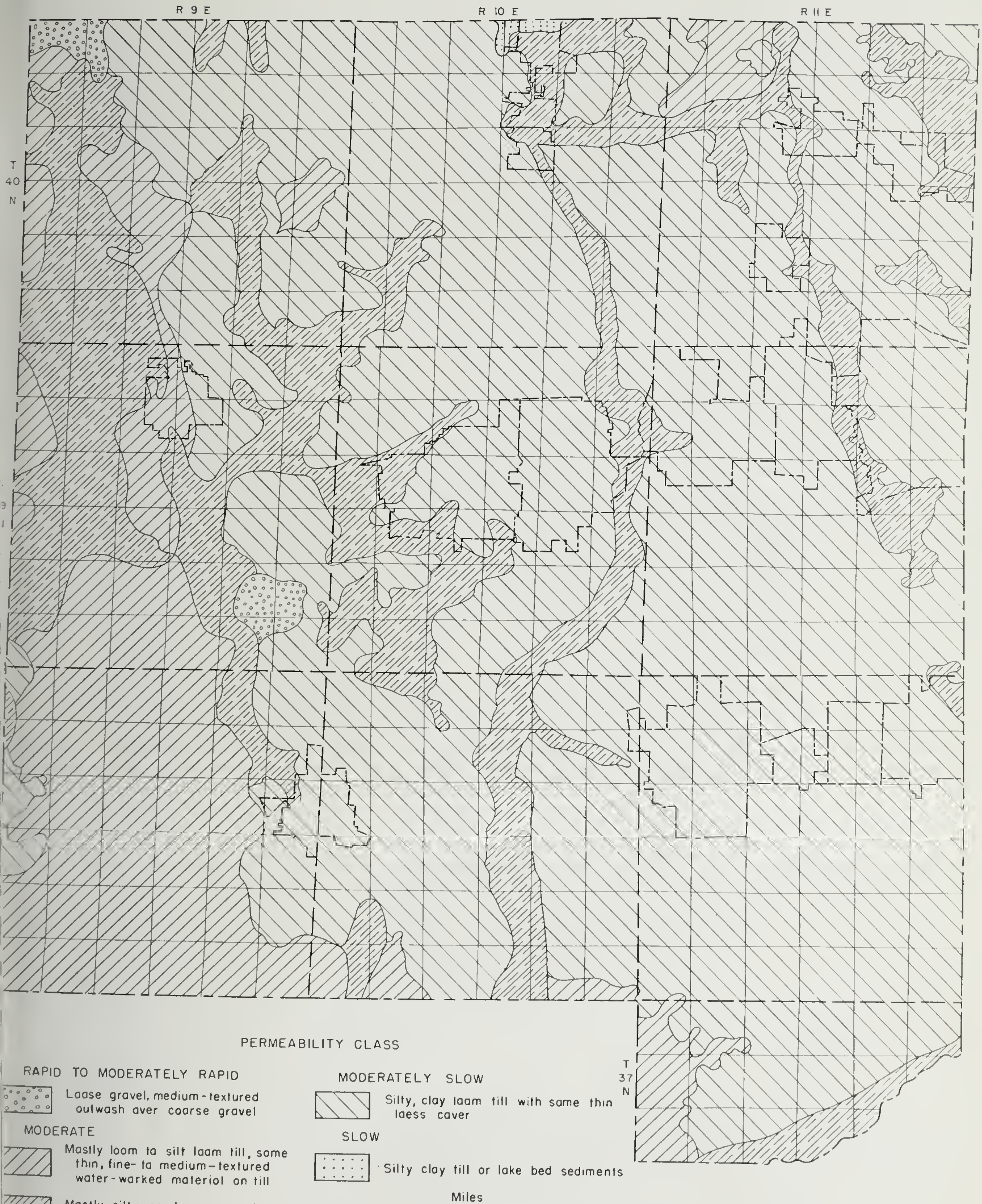

R 9 E
R 10 E
R 11 E
T
40
N
T
37
N
PERMEABILITY CLASS
RAPID TO MODERATELY RAPID
Loose gravel, medium-textured outwash over coarse gravel
MODERATE
Mostly loam to silt loam till, some thin, fine- to medium-textured water-worked material on till
Mostly silty, sandy, or gravelly outwash
MODERATELY SLOW
Silty, clay loam till with some thin loess cover
SLOW
Silty clay till or lake bed sediments
Miles
0
1
2
3

Fig. 10. Permeability of soils and nature of soil substrata.

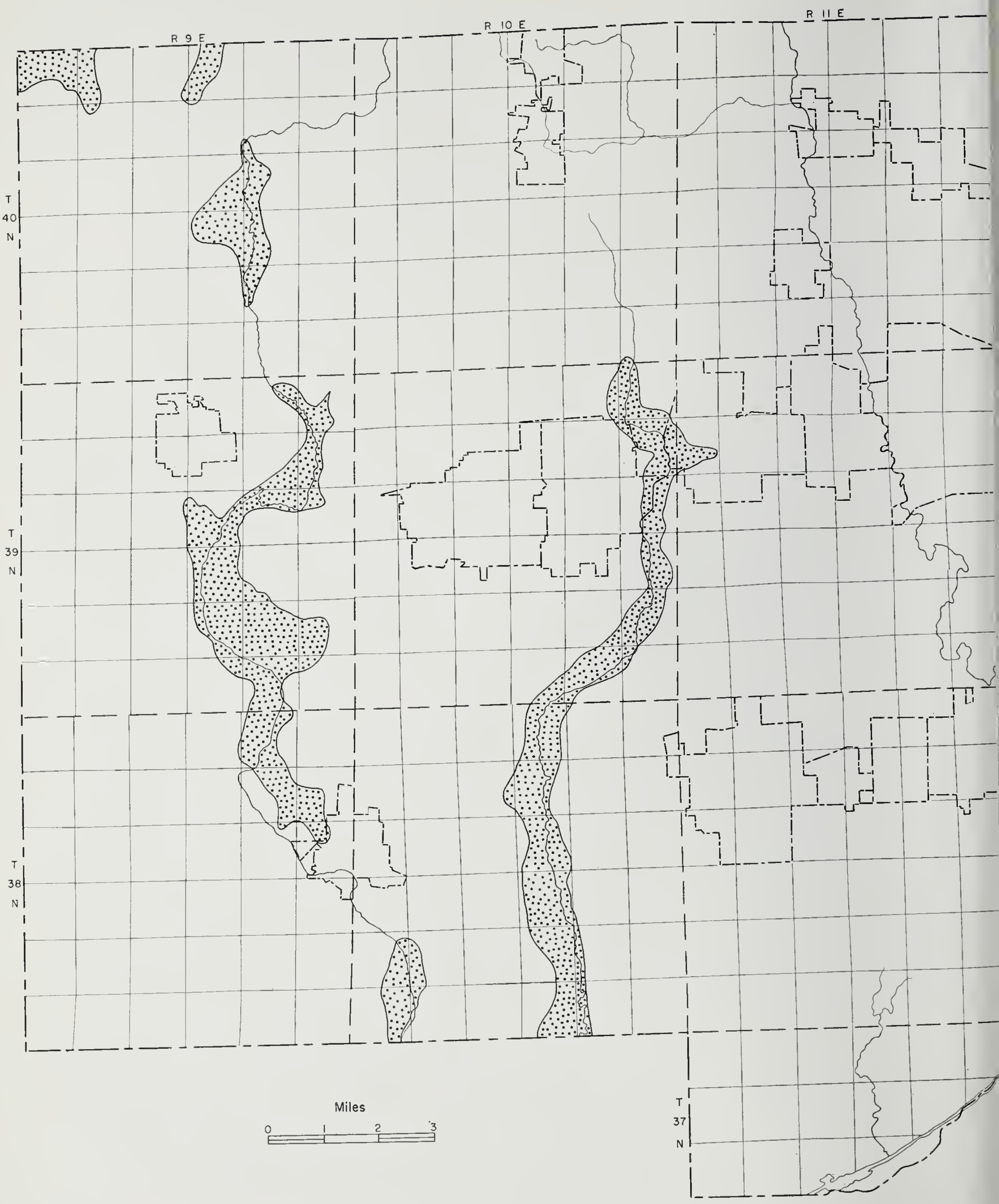


Fig. 11. Distribution of surficial glacial drift aquifers.

River shows the general character of these outwash materials (DUP 38N10E-3.2f; Appendix B).

A map of the permeability of soils and the nature of soil substrata (fig. 10) was constructed from the map of Parent Material and Surface Color of Soils in Northeastern Illinois prepared by the University of Illinois Agricultural Experiment Station (1957), and from data on permeability available in soil type descriptions published by the Department of Agronomy at the University of Illinois. The designation of permeability given to a soil type refers to the least permeable horizon n the soil profile and is based upon empirical data. In most instances, the least permeable horizon is the subtrata (any material below the subsoil which is agriculurally significant).

Table 4 presents the rate of penetration of water under a one-inch head into a moist soil.

Table 4. Rate of Penetration of Water into Soils by Permeability Class

Very slow	Slow	Moderately slow	Moderate	Moderately rapid	Rapid	Very rapid
Rate of penetration, inches per hour						
Less than 0.05	0.05 to 0.2	0.2 to 0.8	0.8 to 2.5	2.5 to 5.0	5.0 to 10.0	More than 10.0

Permeability class

Correlation of the maps of surficial geology (fig. 8) and permeability of soils and nature of substrata (fig. 10) with data obtained from studies of samples from test borings and from well and drillers' logs on the character and thickness of material provides the basis for delineation of surficial glacial drift aquifers favorable for development of moderate to large ground-water supplies (fig. 11).

Interbedded glacial drift aquifers are deposits of sand and gravel which occur either as sheet-like deposits or as lenticular and discontinuous deposits erratically distributed throughout the glacial drift. Commonly, they are separated from the surficial and basal glacial drift aquifers by deposits of glacial till. The general character of the sand and gravel deposits which make up these interbedded deposits is shown by the study of samples from well DUP 40N9E-33.1a (Appendix B).

Cross sections of the glacial deposits (fig. 12) based on sample studies and drillers' logs show that interbedded deposits of sand and gravel are numerous in the West Chicago and older end moraines but are limited in the younger end moraines to the east. The principal interbedded sand and gravel deposit in the western part of DuPage County is the extensive, fairly continuous West Chicago outwash (fig. 12 BB′). The deposits interbedded with the tills of the West Chicago and earlier end moraines are believed to represent extensive buried sheets of outwash deposits. The interbedded de-

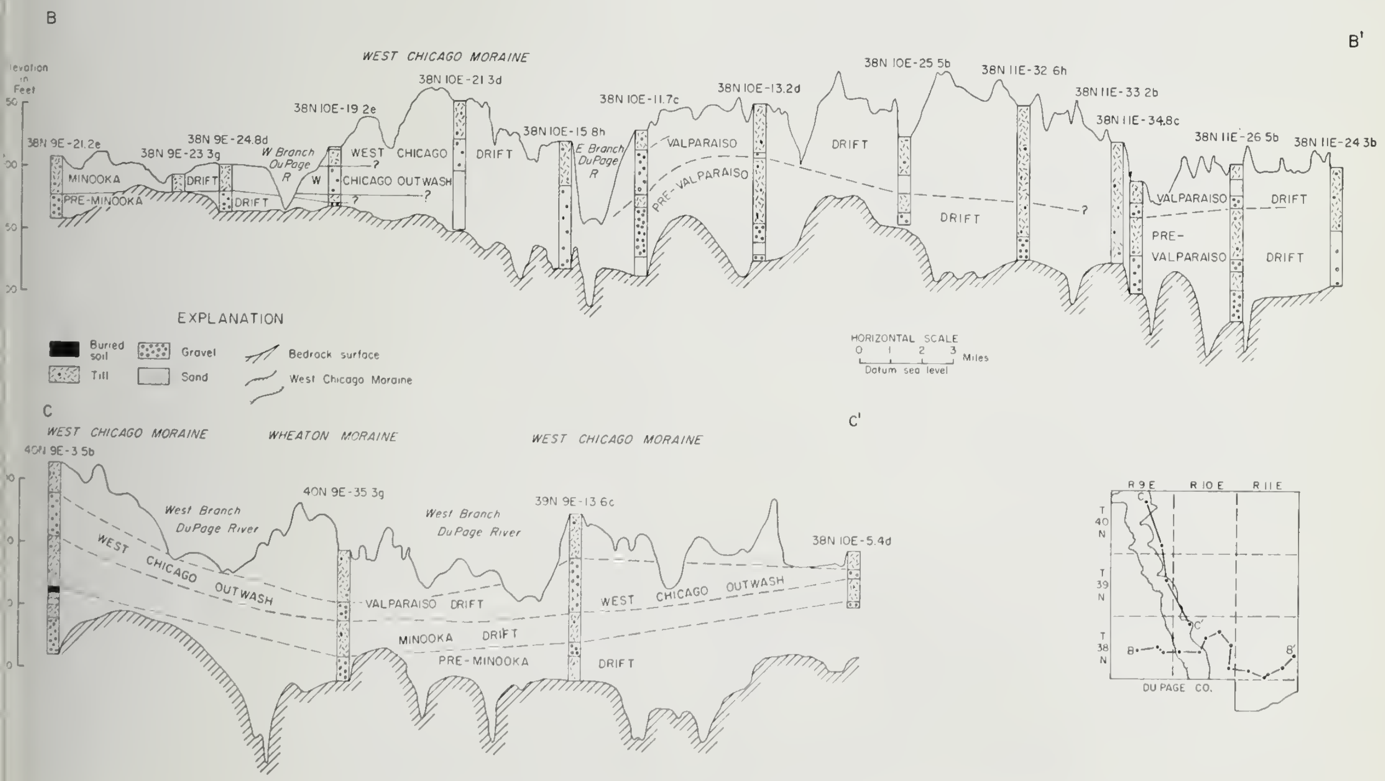


Fig. 12. Cross sections of glacial deposits.

posits of sand and gravel in the later drifts are more lenticular, discontinuous, and erratically distributed.

The scarcity of subsurface data prohibits detailed mapping of individual interbedded deposits of sand and gravel. The occurrence and distribution of these deposits are incorporated in the map of total thickness of sand and gravel in glacial drift, based upon moving averages (fig. 14).

Basal glacial drift aquifers are the sand and gravel deposits at the base of the glacial drift directly above the dolomite in DuPage County. These deposits are commonly coarse-grained and have relatively high permeabilities. A study of samples of drill cuttings from a water well shows the general character of the basal glacial drift aquifers (DUP 38N10E-12.2b; Appendix B).

The extreme ranges in the thickness of basal sand and gravel deposits which commonly occur within short distances, and the unequal distribution of well control make impractical the construction of a map of the thickness and distribution of the basal sand and gravel deposits. A map based upon moving averages (Pelletier, 1958, p. 1036) shows the general distribution of basal sand and gravel deposits in the county (fig. 13). In general, greater thicknesses of basal sand and gravel deposits occur in areas of thicker glacial drift (compare figs. 9 and 13). The basal sand and gravel deposits probably exceed 60 feet in thickness in the north-central part of the county.

Throughout much of Illinois concentration and greater thickness of sand and gravel often result from the channeling of glacial melt-waters in bedrock valleys. The data in table 5 show that the percentage of wells which penetrate basal sand and gravel in DuPage County is slightly smaller in bedrock valleys than in bedrock uplands. Even though the average thickness of basal sand and gravel per penetrating well is slightly greater in bedrock valleys, no significant relationship is found between the occurrence and thickness of basal sand and gravel deposits and bedrock topography in the county.

Table 5. Occurrence and Thickness of Basal Sand and Gravel

	Bedrock upland	Bedrock valley
Total number of wells	328	407
Number of wells which record basal sand and gravel	256	299
Percentage of wells which record basal sand and gravel	78	73
Total thickness in feet of basal sand and gravel deposits recorded by wells	6933	9634
Average thickness in feet of basal sand and gravel deposits per well	27	32

Distribution

The map of total thickness of sand and gravel posits in glacial drift, based on moving averages (f 14) includes all sand and gravel deposits regardless mode of occurrence and continuity. Total thickness sand and gravel greater than 60 feet occurs in t north-central part of the county, the area of thick glacial drift.

The distribution of glacial drift aquifers in DuPa County is shown in figure 15. Throughout most of t county these aquifers are scattered in occurrence, ran from 20 to 40 feet in thickness, and vary widely extent and permeability. Glacial drift aquifers whi locally exceed 40 feet in thickness are concentrated the north-central part of the county. Locally in t southwestern, southeastern, and eastern parts of t county, glacial drift aquifers are generally thin absent.

The limitations of the geologic and hydrologic da permit only generalized interpretations of the characte occurrence, and distribution of the glacial drift aquife Additional data are necessary before the glacial dri aquifers in DuPage County can be better defined ai their potential as sources of ground water more pı cisely evaluated.

Silurian Dolomite Aquifer

The Silurian dolomite aquifer is made up of t rocks of the Niagaran and Alexandrian Series of Sil rian age. It occurs directly beneath the glacial dri throughout all of DuPage County with the exceptio of a narrow strip in the north-central part of the coun where a deep bedrock valley has been cut through tl dolomite into the Maquoketa Formation (fig. 7). Dept to the top of the Silurian dolomite aquifer vary wide within short distances and can be estimated general from the map of thickness of the overlying unconso dated deposits (fig. 9), or by use of the bedrock topo raphy map and appropriate topographic maps (pl. 1 The configuration of the upper surface of the Siluria dolomite aquifer is shown by the map of bedrock topo raphy at a contour interval of 20 feet (pl. 1). Tl thickness of the Silurian dolomite aquifer in the rel tively unpopulated western half of the county rang from 50 to 100 feet (fig. 16). It thickens to the ea and southeast and is 150 to 200 feet thick in the sout eastern part of the county. Thicknesses of greater tha 200 feet occur in the Downers Grove-Hinsdale ar where the Silurian dolomite aquifer is heavily develope for industrial and municipal supply. A maximum thic ness of 252 feet is reported in the Clarendon Hills Cit Well No. 4 (DUP 38N11E-11.5d). Thicknesses of le than 50 feet are limited to the northwestern and soutl

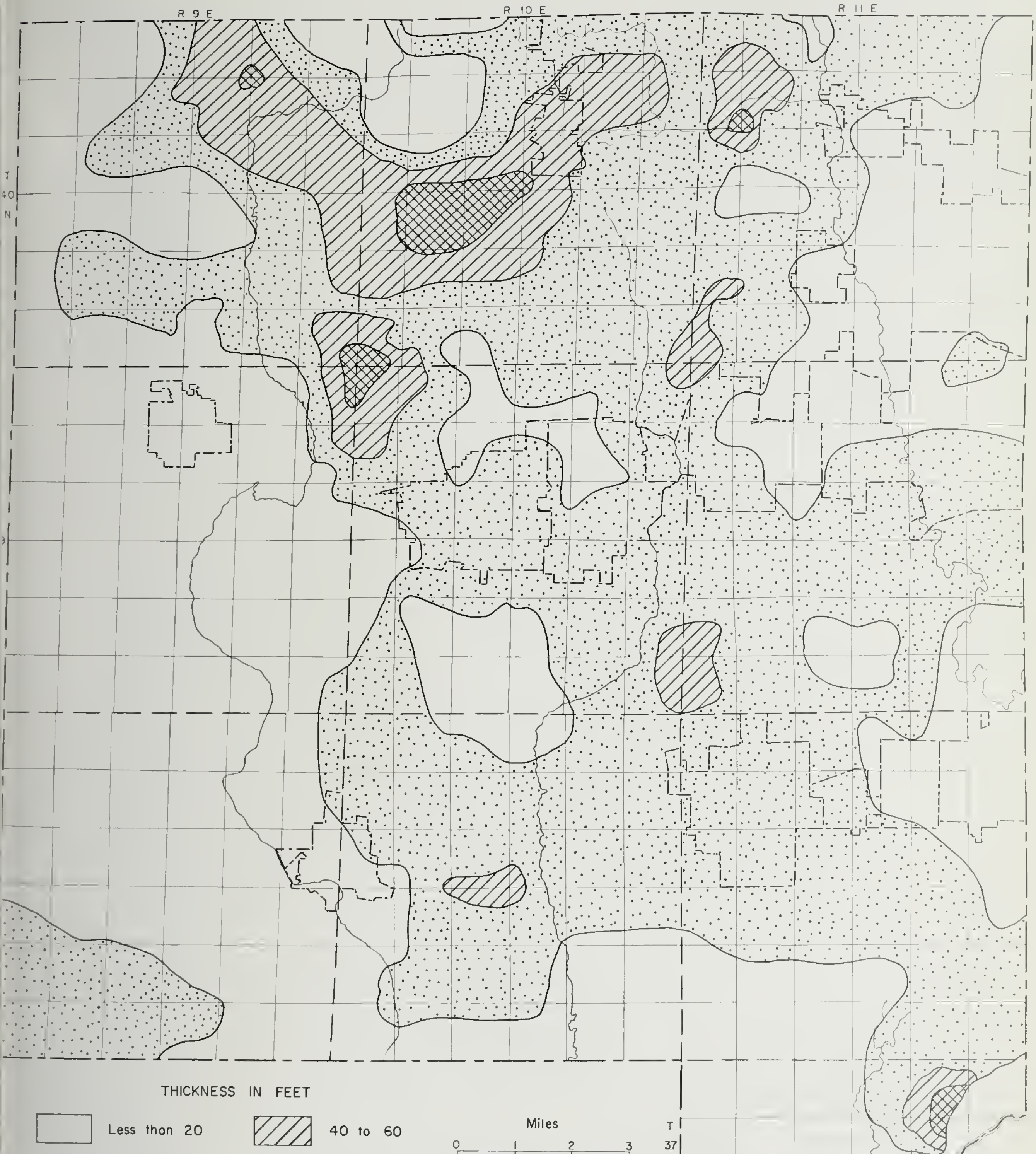


Fig. 13. Thickness of basal sand and gravel deposits, based on moving averages.

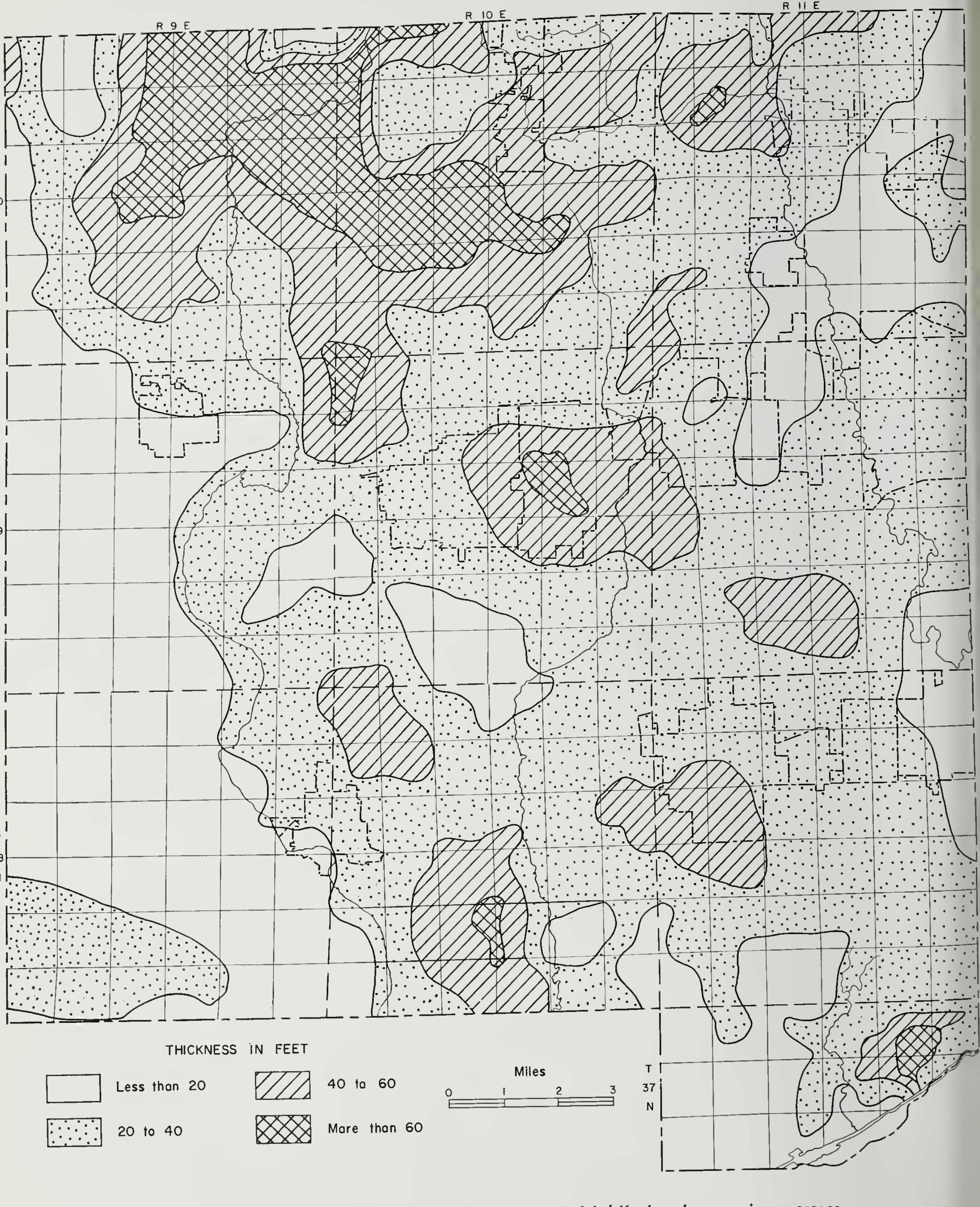


Fig. 14. Total thickness of sand and gravel deposits in glacial drift, based on moving averages.

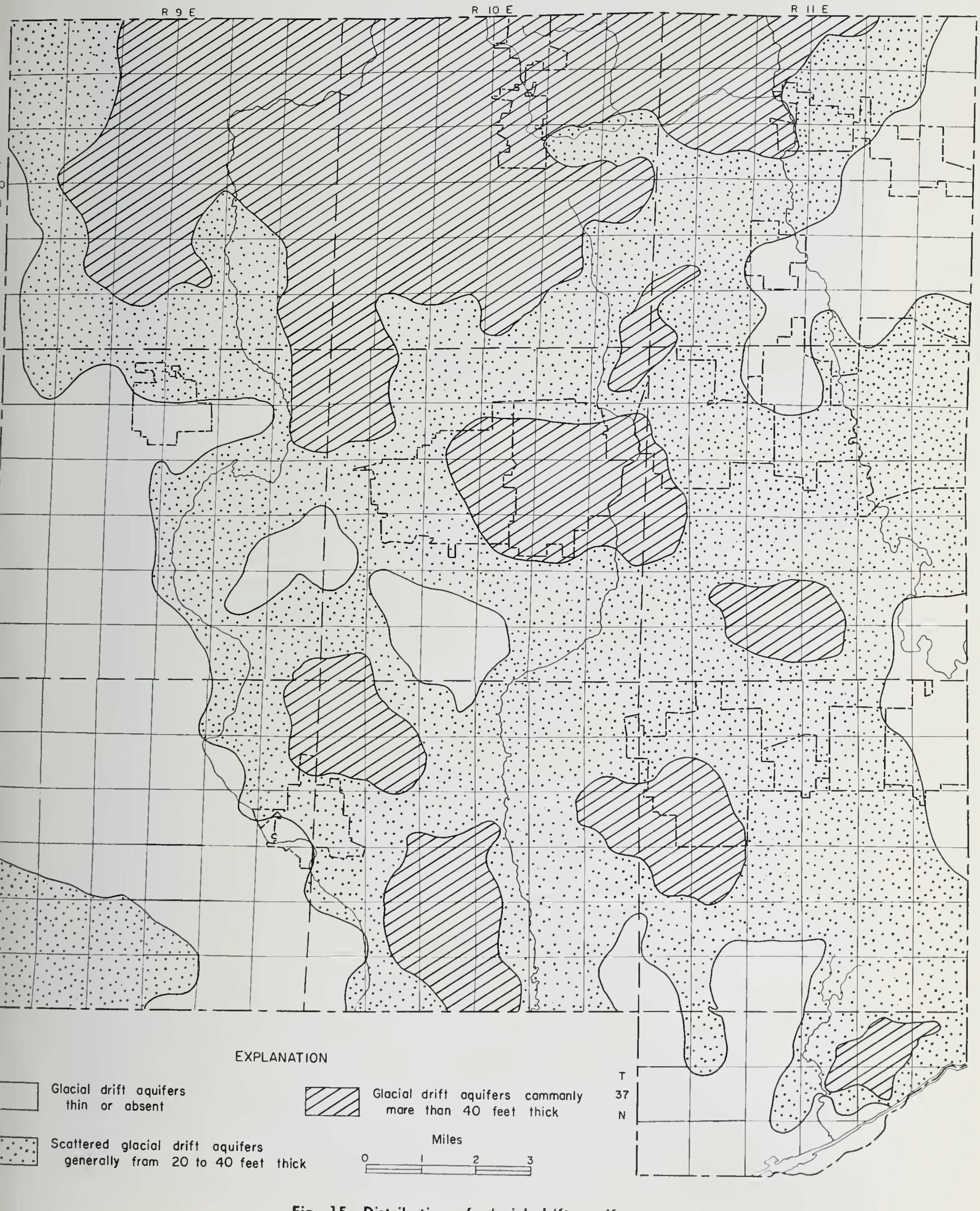

R 9 E
R 10 E
R 11 E
T
37
N
EXPLANATION
Glacial drift aquifers thin or absent
Scattered glacial drift aquifers generally from 20 to 40 feet thick
Glacial drift aquifers commonly more than 40 feet thick
Miles
0
1
2
3

Fig. 15. Distribution of glacial drift aquifers.

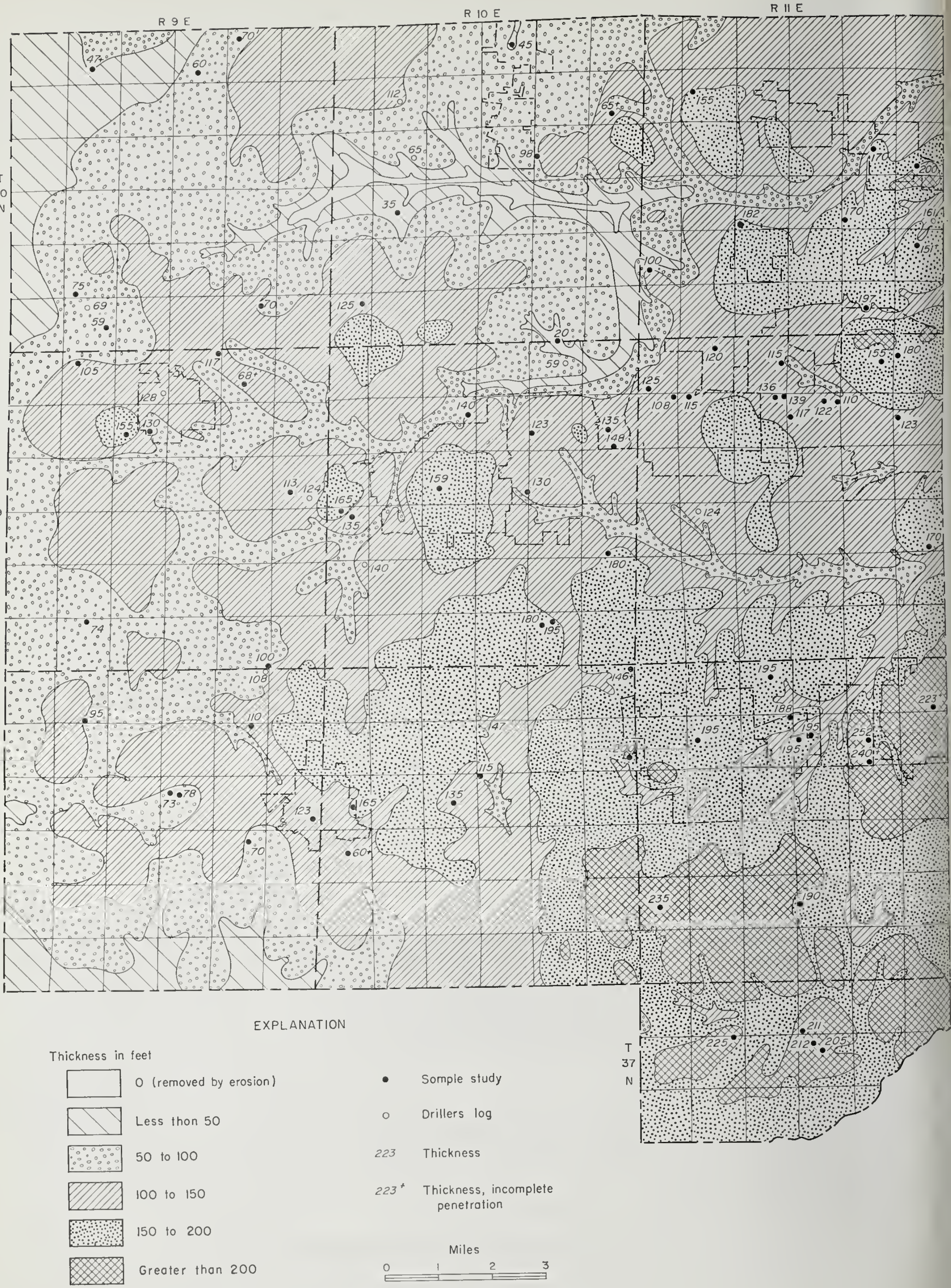


Fig. 16. Thickness of Silurian dolomite aquifer.

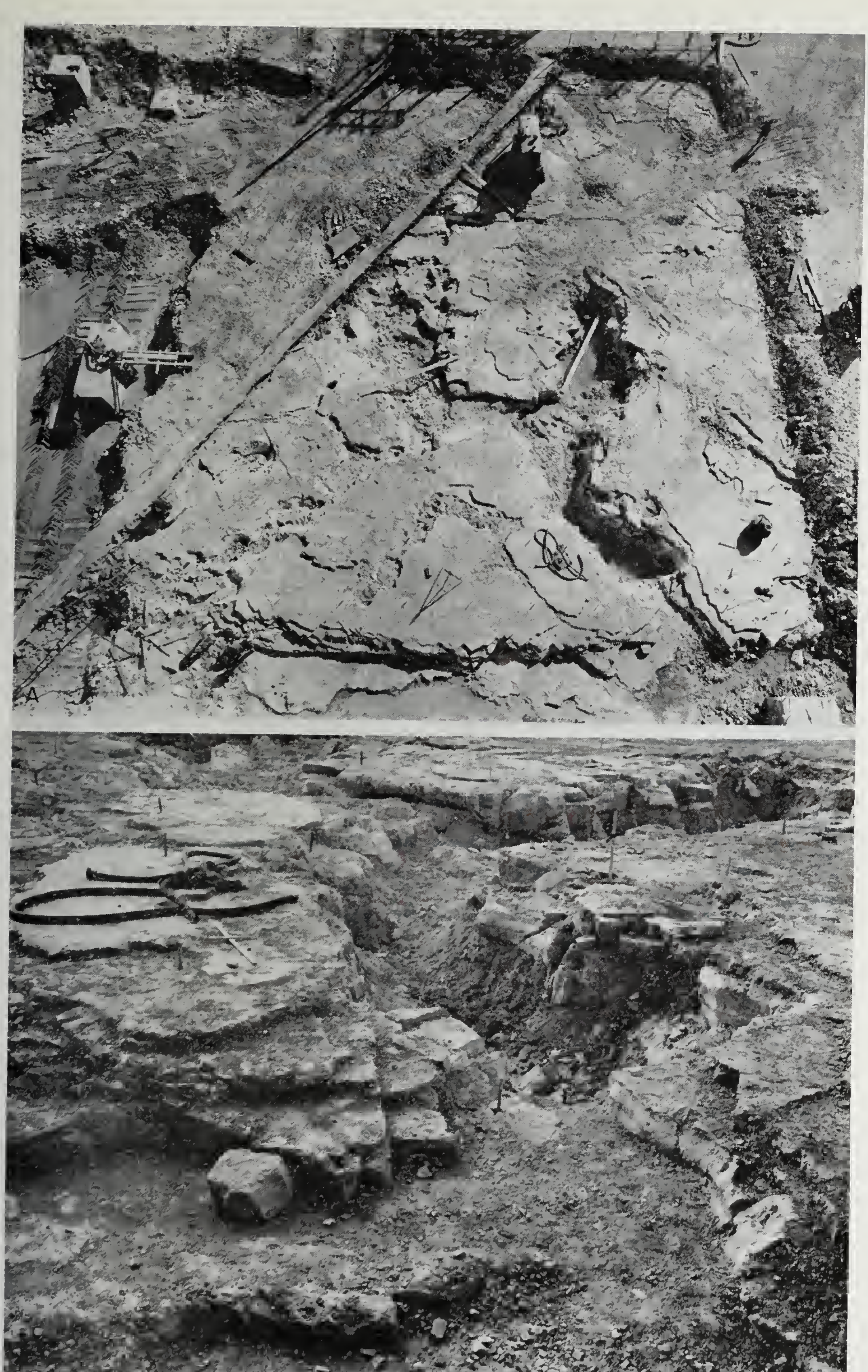


Fig. 17. Aerial and ground views of joint-controlled solution cavities in the Silurian dolomite aquifer (photographs courtesy of the Commonwealth Edison Company).

western part and along the bedrock valley in the north-central part of the county.

Water-bearing Properties

Ground water in the Silurian dolomite aquifer is stored in openings in the dolomite and moves through a complex network of interconnected openings. Most of the openings in the dolomite are secondary in origin and were formed after the deposition and consolidation of the rocks. The influence of primary openings upon ground water in the Silurian dolomite aquifer is considered negligible. The most numerous types of secondary openings are joints and fractures which were produced in the dense and brittle dolomite by deformational forces and later enlarged by solution. The total void space represented by these features is, however, relatively small compared with the total volume of the rock.

Observations of the joints, fractures, and solution cavities in quarries, outcrops, and tunnels throughout the region provide an insight as to their character in the Silurian dolomite aquifer beneath the glacial drift in DuPage County. Many of the joints appear tight but many are fairly wide, and joints up to 12 inches in width have been measured locally (personal communication, Don U. Deere). No regularity of spacing of joints and fractures is obvious in the quarries and outcrops studied throughout the region. The density and distribution of joints and fractures in the Silurian dolomite aquifer in DuPage County cannot be determined quantitatively because of the glacial drift cover.

Enlargement of joints, fractures, and bedding planes by solution has taken place. Some openings enlarged by solution are filled with dense clay or shale; however, most do not contain fill material and are open to ground-water movement. At places, widening by solution occurs where joints and fractures intersect shale or shaly dolomite beds. Smaller horizontal solution openings exist along bedding planes particularly above shale or shaly zones.

In a few exposures in the region, exceptionally large joint-controlled cavities occur. The solution cavities illustrated in figure 17 were uncovered during excavation for foundation construction along the Des Plaines River near the southern border of DuPage County. Some of these clay-filled cavities reach 30 feet in width and extend to depths of 125 feet.

Exposures of the dolomite show that, in general, enlargement of the joints and fractures by weathering and solution has been greater in the upper part of the rock. Many of the openings narrow with depth and thin to fine cracks or disappear. Locally, the relatively impermeable shales of the Maquoketa Formation are the lower limit of solution enlargement. The zone of solution-enlarged openings in the upper part of t
Silurian dolomite aquifer is thought to be related to
zone of increased solution near a fluctuating water tal
when the dolomite was at land surface in the geolog
past. Solution enlargement probably was facilitated
the higher concentrations of carbon dioxide and orgar
acids contained in the percolating water.

The upper part of the Silurian dolomite aquifer
believed to be a zone of relatively high permeabili
and a major water-yielding interval. Many drillers
DuPage County report that the upper part of t
dolomite is a reliable water-yielding zone and that it
the most productive part of the aquifer. The reliabili
of this zone is also indicated by plotting number
wells versus depth of penetration into the dolomite f
655 wells drilled in DuPage County (fig. 18). Tl
figure shows that 78 percent of the wells are comple
in the upper 60 feet of the dolomite. The great
number, 221, penetrate only 20 to 40 feet into the ro

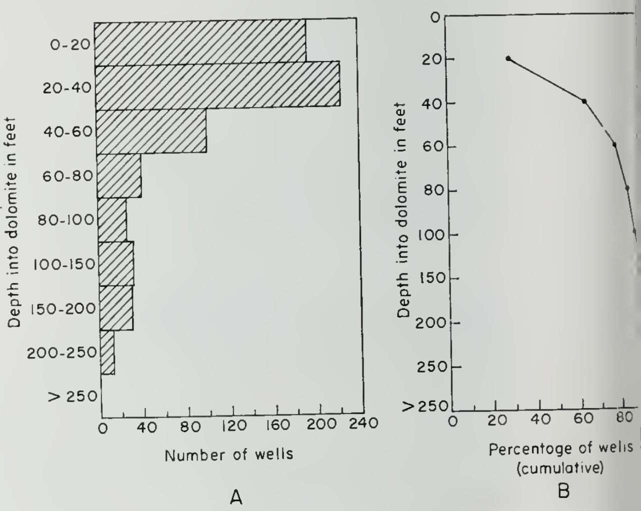


**Fig. 18. Number (A) and cumulative percentage (B) of w
versus depth of penetration into Silurian dolomite aquifer.**

An analysis of temperature and flow-velocity logs
tained from 10 selected wells shows a significant wat
yielding zone in the upper part of the Silurian dolon
aquifer and some additional zones at greater dept
When correlated with information obtained from v
drillers on depths to probable crevice and water-yie
ing zones and study of samples of the drill cuttin
fairly reliable determinations of the location of per
able zones in the Silurian dolomite aquifer were possi
Even though temperature and flow-velocity logs
be used to locate the water-yielding zones in wells, n
refined techniques of geophysical logging are necess
to define these zones more precisely and to prov
information on the type of openings in the dolon
Additional geologic, geophysical, and hydrologic

ewise are necessary to evaluate more fully the water- elding zone in the upper part of the Silurian dolomite uifer.

The capacity of the Silurian dolomite aquifer to trans- it ground water is influenced strongly by the size, imber, and interconnection of the joints, fractures, d solution cavities. Extensive development and inter- nnection of these openings are indicated by the reli- ility of the dolomite as a source of ground water, by e high yields of wells drilled into the dolomite, and the relatively uniform piezometric surface of the ter in the dolomite. The effect of pumping wells on water levels in observation wells at considerable stances also indicates a widely interconnected network openings in the Silurian dolomite aquifer.

With unlimited recharge, the quantity of water which n be produced from a well depends chiefly upon the mber and size of the water-yielding openings inter- cted during drilling of the well. The probability that well may penetrate the Silurian dolomite aquifer npletely without hitting any openings always exists, d some element of chance is always involved in the rch for water. However, few "dry" holes have been ported in DuPage County and this supports the opin- n that joints and fractures are open, abundant, and erconnected.

The frequency analysis of specific capacities of wells sus deepest stratigraphic unit reached by the wells 59–60) shows that basic differences in productivity ur between the rocks of the Niagaran Series, the xandrian Series, and the Maquoketa Formation ere these units overlie each other. Unfortunately, le data are available where the Alexandrian Series the Maquoketa Formation occurs directly below the cial drift; therefore, the water-yielding character either of these as a separate unit is difficult to evalu- .

n the basis of the frequency analysis, two distinct ifer units are recognized within the Silurian dolo- e aquifer in DuPage County: 1) the Niagaran aqui- , and 2) the Alexandrian aquifer. The weathered e with solution-enlarged openings in the upper part the dolomite is developed in both of these units re they directly underlie the glacial drift.

GARAN AQUIFER

he Niagaran aquifer consists of the rocks of the garan Series of Silurian age and forms most of the rock surface in DuPage County. This aquifer ches a maximum thickness of 175 feet in the south- tern part of the county (fig. 19). Thicknesses of 100 150 feet are common throughout much of the eastern -third of the county. The Niagaran aquifer thins idly to less than 50 feet in most of the western one-third of the county and has been removed completely by erosion in the southwestern part and along the major bedrock valley in north-central DuPage County.

The Niagaran aquifer is the most heavily developed part of the Silurian dolomite aquifer, and most wells terminate in these rocks. Lithologic and structural changes in the Niagaran aquifer cause a lack of uniformity in its water-bearing properties.

The weathered zone with solution-enlarged openings in the upper part of the Silurian dolomite aquifer is most extensively developed in the dolomite of the Niagaran aquifer because of the widespread occurrence of this aquifer at the bedrock surface throughout most of the county. On the basis of the geologic evidence, this zone with solution-enlarged openings is believed to be a zone of relatively high permeability within the aquifer that influences well yields considerably. Available well production data are inadequate to establish quantitatively the effect of this zone upon well yields in the Niagaran aquifer.

Major lithologic and structural changes in the character of the Niagaran aquifer are associated with reefs. Reef cores are made of relatively clean dolomite, and steep dips are present in the flanking beds. Statistical analysis of well yields versus thickness of reef penetrated by a well suggests that well yields are related to thickness of reef-bearing strata penetrated (see Statistical Analysis of Geologic Controls, p. 41). In order to establish more firmly the relationship of reefs to well yields, the distribution of reefs in the Niagaran aquifer must be known. The presence of dolomitized reefs in the dolomite of the Niagaran aquifer is difficult to determine by commonly used methods of subsurface investigation but can be inferred from studies of samples of well cuttings. Examination of a series of gravity profiles run above the reef at Thornton reveals the presence of a negative gravity anomaly and suggests that detailed gravity surveys may be used to locate and delineate these reefs (personal communication, L. D. McGinnis).

Basal Unit

The shaly basal beds of the Niagaran Series form a distinct unit within the Niagaran aquifer where they retard recharge to the underlying aquifer and in these areas can be designated as the basal unit of the Niagaran aquifer. These basal beds are present throughout most of DuPage County with the exception of the southwestern part (fig. 20A). A maximum thickness of 35 feet occurs in the southeastern part (fig. 20B).

Hydrologic analysis of the West Chicago pumping cone shows that recharge to the Silurian dolomite aquifer in this area is restricted compared with other areas in the county. The lower recharge rate may have resulted from the limiting effect of the shaly basal beds

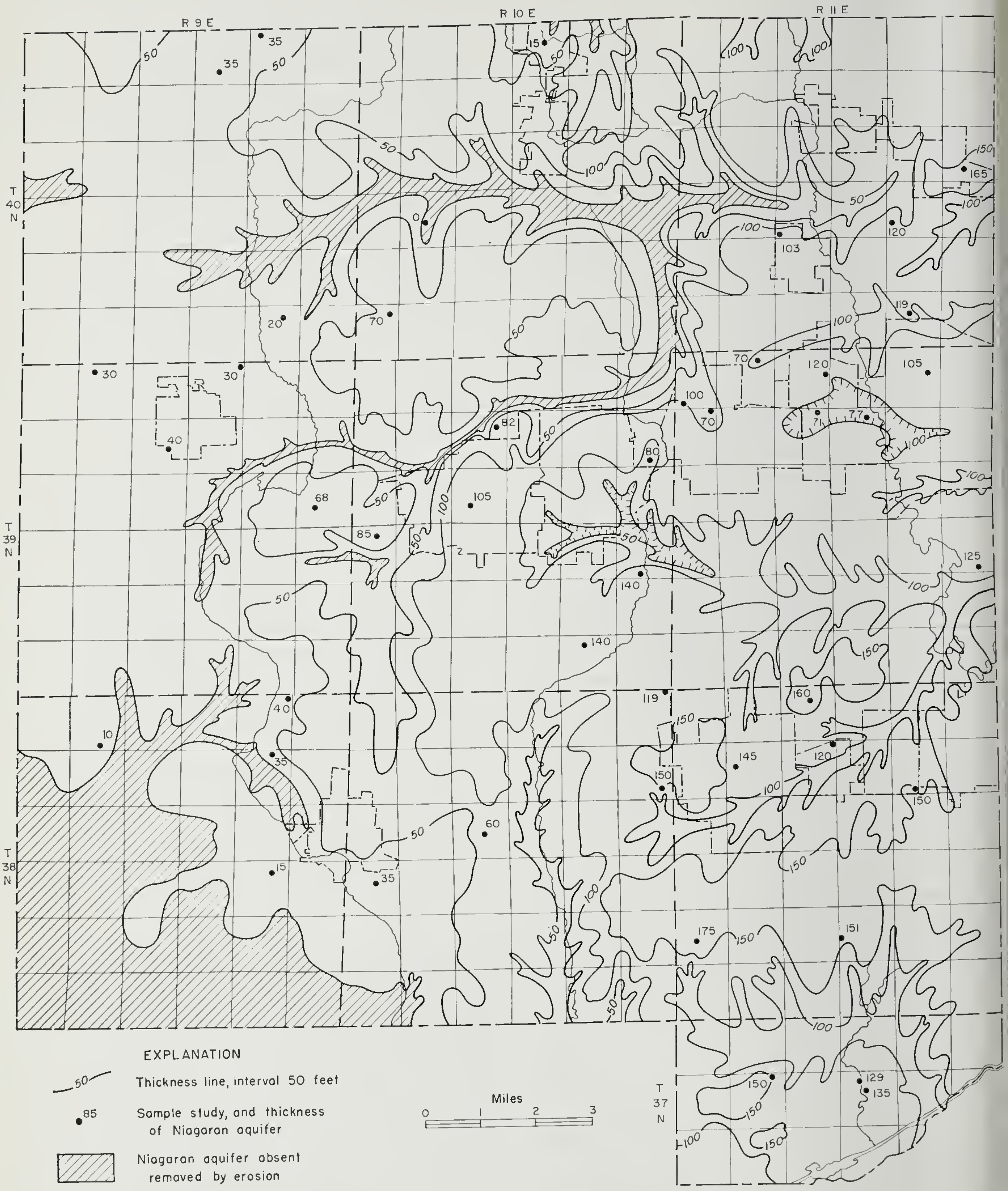


Fig. 19. Thickness of Niagaran aquifer.

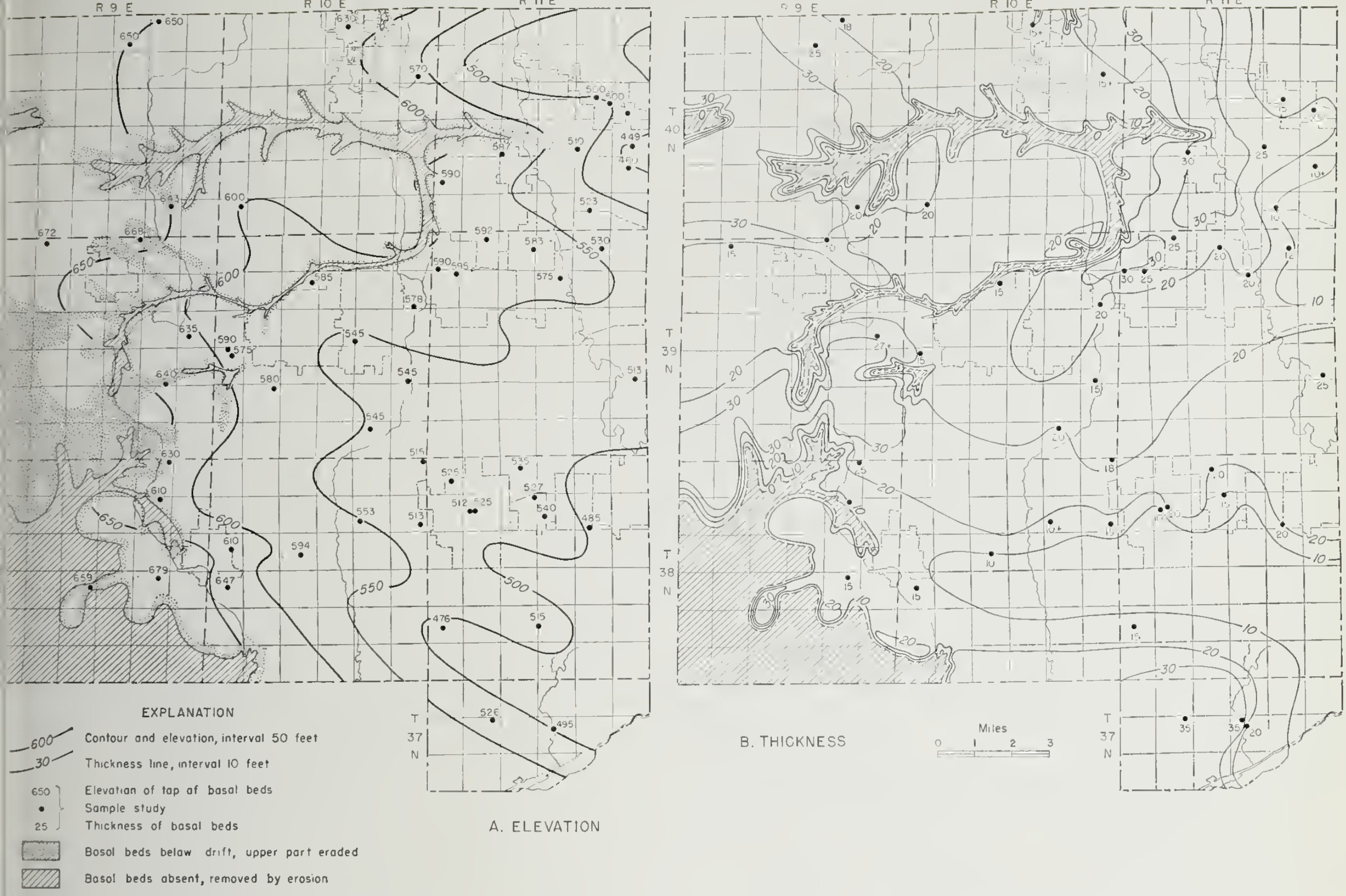

R 9 E
R 10 E
R 11 E
T 40 N
T 39 N
T 38 N
T 37 N
EXPLANATION
600 Contour and elevation, interval 50 feet
30 Thickness line, interval 10 feet
650 Elevation of top of basal beds
● Sample study
25 Thickness of basal beds
Basal beds below drift, upper part eroded
Basal beds absent, removed by erosion
A. ELEVATION
B. THICKNESS
Miles
0 1 2 3

Fig. 20. Top elevation (A) and thickness (B) of the basal beds of the Niagaran Series.

the Niagaran Series upon the development of a zone h solution-enlarged (hence permeable) openings in upper part of the dolomite in the past. In the area ompassed by the West Chicago pumping cone, there- e, and in areas in the county where geohydrologic iditions are similar, the basal beds of the Niagaran ies may act hydraulically as a distinct unit (the al unit of the Niagaran aquifer) and may retard harge to the underlying aquifer. Data necessary to iblish the geohydrologic character of the basal beds the Niagaran Series and their hydraulic influence in Silurian dolomite aquifer are not available through- most of the county.

xandrian Aquifer

he Alexandrian aquifer includes all the rocks of the xandrian Series of Silurian age and is present in t of DuPage County (fig. 21A). The Alexandrian ifer directly underlies the Niagaran aquifer through- most of the county, and many of the wells withdraw und water from both of these units. In the south- tern part of the county, however, the Alexandrian aquifer constitutes the entire thickness of the Silurian dolomite aquifer.

The thickness of the Alexandrian aquifer, as reported in 49 wells, averages 57 feet and reaches a maximum of about 90 feet locally in the county (fig. 21B). Thicknesses in excess of 80 feet occur locally in the eastern third of the county where the Alexandrian aquifer is overlain by thick dolomite of the Niagaran aquifer. Fortunately, however, greater thicknesses of the Alexandrian aquifer also occur southwest of West Chicago where the overlying Niagaran aquifer is very thin. The importance of the Alexandrian aquifer perhaps is greatest in southwestern DuPage County where it is the only unit of the Silurian dolomite aquifer available for development. This area is now one of the least populated parts of the county and present development of the Alexandrian aquifer as a source of ground water is limited.

Statistical Analysis of Geologic Controls

Analysis of the complex system of geologic variables, such as the lithologic, structural, and topographic char-

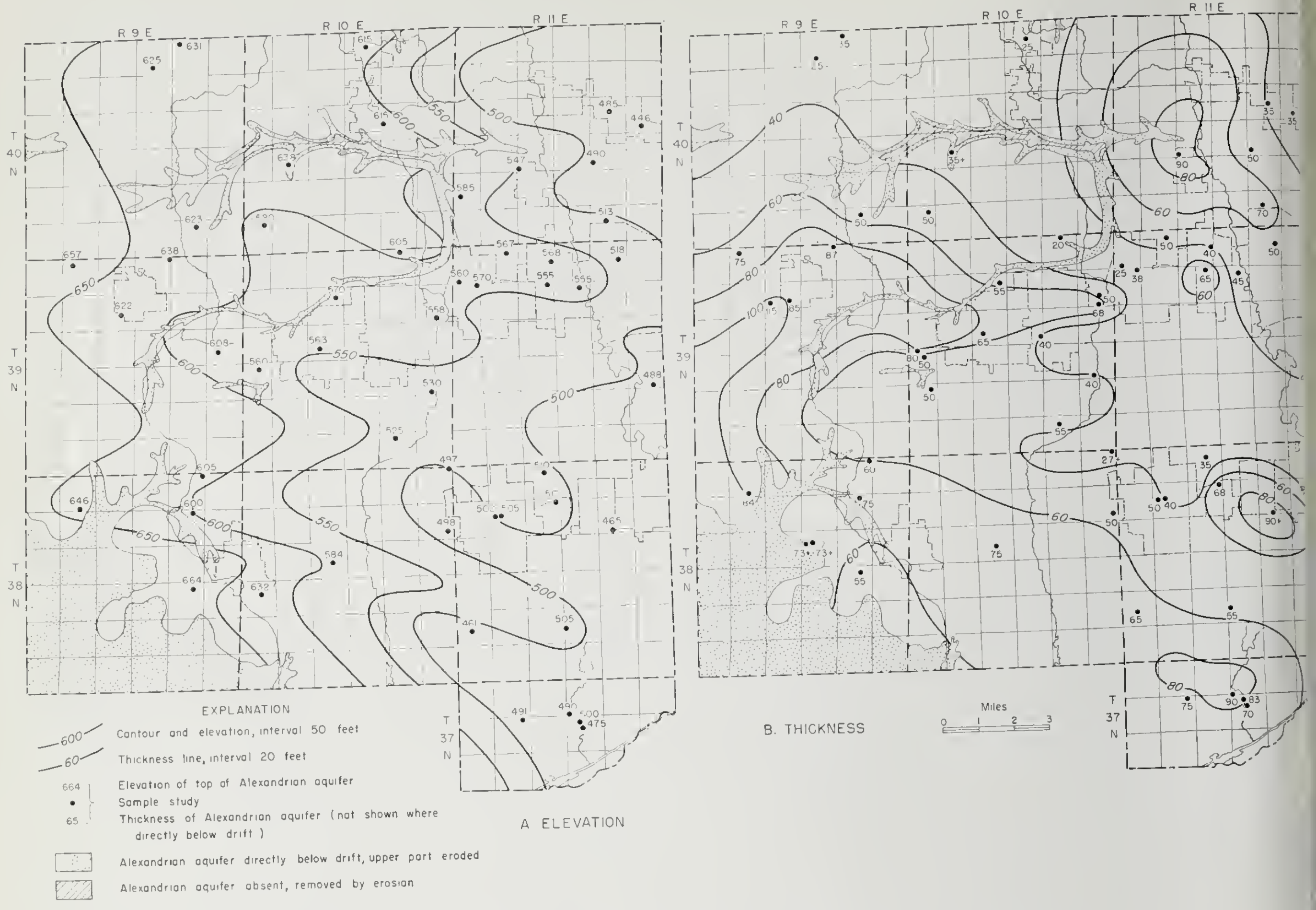

R 9 E
R 10 E
R 11 E
T 40 N
T 39 N
T 38 N
T 37 N
EXPLANATION
600 Contour and elevation, interval 50 feet
60 Thickness line, interval 20 feet
664 Elevation of top of Alexandrian aquifer
Sample study
65 Thickness of Alexandrian aquifer (not shown where directly below drift)
Alexandrian aquifer directly below drift, upper part eroded
Alexandrian aquifer absent, removed by erosion
A. ELEVATION
B. THICKNESS
Miles
0 1 2 3

Fig. 21. Top elevation (A) and thickness (B) of the Alexandrian aquifer.

acter of the Silurian dolomite aquifer and its relationship to well yields, was made by a quantitative method of statistical analysis. Selection of the geologic factors analyzed was based upon their surmised relationships to ground-water production, which resulted from the study of the aquifer in DuPage County, and upon established or suggested relationships to ground-water or petroleum production in other carbonate terranes throughout the country. The probable influence of the character of the immediately overlying unconsolidated material upon well yields in the Silurian dolomite aquifer was also evaluated because of the local hydraulic interconnection of the dolomite and glacial drift.

Correlation and regression analyses (Snedecor, 1950) were made, with assistance from the University of Illinois automatic electronic digital computer, to determine if significant relationships exist between the specific capacities of wells and several geologic controls. Wells were grouped into the 13 categories in table 6. The specific capacities of wells in each category, expressed in six forms, were studied in relation to the seven geologic controls in table 6.

Simple linear correlation coefficients were comput for well categories 1 and 3 versus geologic controls *1*, *3*, *4*, and *7*. Specific capacity in this case was express in forms *a*, *b*, *c*, and *d*. The same procedure was follow for well category 2 with one exception: geologic contr *5* was included. For well categories 4 through 12, t correlations were computed for specific capacity for *a* through *f* versus the seven geologic controls with t exceptions: control *7* was not applicable in well ca gories 4 and 5. In the case of well category 13, t correlations were determined for specific capacity for *a* and *b* versus the thickness of reef penetrated by wel

The simple correlation analyses provided a total 432 separate linear correlation coefficients for well ca gories and geologic controls. The "variance-ratio" t described by Snedecor (1950) was used to establish t probability level of significance for these relationshi Standard deviations of specific capacities were compar with corresponding standard errors of estimate. Diff ences in these two standards were expressed as a perce of the standard deviation to provide a measure of pr tical significance of relationships.

Table 6. Well Categories, Geologic Controls, and Specific Capacity Forms

Well categories

The deepest unit penetrated by the well is the Niagaran
The deepest unit penetrated by the well is the Alexandrian
The well terminates above the basal beds of the Niagaran Series
The glacial deposits penetrated by the well immediately above bedrock are predominately tight till
'he glacial deposits penetrated by the well immediately above bedrock are predominately loose till
'he well is in a bedrock valley and anticline
'he well is in a bedrock upland and syncline
'he well is in a bedrock upland and anticline
'he well is in a bedrock valley and syncline
'he glacial deposits penetrated by the well immediately above bedrock are predominately sand and gravel
'he deepest unit penetrated by the well is the Maquoketa Formation
'he well terminates below the basal beds of the Niagaran Series
rilling-cuttings samples indicate well encountered a reef

Geologic controls

hickness of glacial drift at well site
hickness of units penetrated by well
hickness of Silurian age dolomite at well site
hickness of Niagaran unit penetrated by well
hickness of Alexandrian unit penetrated by well
hickness of Maquoketa Formation penetrated by well
hickness of basal sand and gravel deposits at well site

Specific capacity forms

n/ft, adjusted
n/ft, actual
n/ft per foot of penetration, adjusted
n/ft per foot of penetration, actual
n/ft per foot of Silurian age dolomite penetration, adjusted
n/ft per foot of Silurian age dolomite penetration, actual

number of multiple correlation relationships were
uted following the study of simple correlations.
geologic controls having the best correlation with
categories were used in the multiple relationships.
following multiple relationships were determined
ell category 1 using: specific capacity form *a* versus
gic controls *2* and *3*; *2* and *4*; *3* and *4*; *2, 3,* and *4*;
fic capacity form *b* versus geologic controls *1* and *2*;
3; *1* and *4*; *2* and *3*; *2* and *4*; *3* and *4*; *1, 2,* and *3*;
and *4*; *1, 3,* and *4*; *2, 3,* and *4*; *1, 2, 3,* and *4*;
specific capacity form *d* versus geologic controls
4.

the case of well category 2 each of the specific
ity forms *a, b, c,* and *d* were expressed in a mul-
relationship with geologic controls *1* and *7*. The
ple relationships were determined for well category
ng specific capacity form *a* versus geologic controls
3; and specific capacity form *b* versus geologic
ols *1* and *2*; *1* and *3*; *2* and *3*; *1, 2,* and *7*.

ltiple correlations were computed for all possible
nations of two or three geologic controls *1, 2, 3, 4,*
6 with specific capacity forms *a* and *b* of well
ory 4. The same procedure was followed for specific capacity forms *c* and *d* using geologic controls *2, 3, 4, 5,* and *6,* and for specific capacity form *f* using geologic controls *2, 5,* and *6.* Multiple relationships for other well categories were not determined because the simple correlations were very low.

Variance-ratio tests of significance were performed to provide information for judging whether the multiple correlations were significantly better than the simple correlations. Standard errors of estimate for simple correlations were compared with standard errors of estimates for multiple correlations to provide a practical basis for accepting or rejecting statistically significant multiple correlations.

The "analysis of variance" technique described by Snedecor (1950) was employed to test for differences between the average specific capacities of well categories. This method terminates with a variance-ratio test of significance which provides a basis for judging whether differences in average specific capacity are statistically significant.

Statistical analysis indicates that significant correlations exist between specific capacities, adjusted and unadjusted, of wells and 1) the total thickness of Silurian age dolomite at well site, 2) thickness of Niagaran unit penetrated by a well, and 3) thickness of reef penetrated by a well. Of equal, if not greater, importance is the fact that many of the geologic factors selected do not have relationships with well yields that are statistically significant. The statistical analysis, therefore, has pointed out those geologic factors which should be rejected and those which should be subjected to further study.

The correlation between thickness of the dolomite of Silurian age at the well site and well yields is expectable and stresses the importance of the map of the thickness of the Silurian dolomite aquifer (fig. 16) in the exploration for water supplies in the county. The relationship between thickness of the Niagaran Series penetrated by a well and well yield accents the need for knowledge of the distribution (fig. 7) and thickness (fig. 19) of the Niagaran aquifer. The necessity for additional information on the effect of reefs upon well yields and the distribution of reefs within the Silurian dolomite aquifer is made evident by the correlation of thickness of reef penetrated by a well and well yield.

The statistical analysis of geologic factors influencing well yields in the Silurian dolomite aquifer and the investigation of the water-bearing properties of the dolomite reveal a highly complex aquifer system in which the effect of an array of geohydrologic variables must be evaluated. The methods of statistical analysis used in this study established significant relationships which, when used with a knowledge of the geohydrologic properties of the dolomite and the information obtained by hydrologic analysis, provide a basis for quantitative evaluation of the Silurian dolomite aquifer.

Confining Beds of the Maquoketa Formation

The relatively impermeable shales of the Maquoketa Formation act as a partial barrier to the downward movement of ground water from the Silurian dolomite aquifer into the deeper Cambrian-Ordovician aquifer. Rocks of the Maquoketa Formation occur throughout the county. The upper surface of the Maquoketa Formation is an erosional surface of relatively high relief (fig. 22A) and depths to this surface are difficult to predict accurately. This marked relief causes thickness of the Maquoketa Formation to vary widely within short distances. Thickness of the Maquoketa Formation as determined from sample studies ranges from 85 to 227 feet and averages about 175 feet (fig. 22B).

The effectiveness of the Maquoketa Formation as a barrier depends mainly upon the general character, thickness, and distribution of the upper, middle, and lower units which are shown in generalized form in figure 23. The high proportion of shale in the basal unit indicates that this is the least permeable of the units. Ground water from the dolomite beds of the middle and upper units locally supplements the supply availa
from the dolomite of Silurian age.

The shales in the Maquoketa Formation frequent
swell and cave, and commonly are cased in wells whi
are drilled to the deeper aquifers.

Cambrian-Ordovician Aquifer

The Cambrian-Ordovician aquifer (Suter et al., 195
includes, from the top down, the following geolo
units: Galena, Decorah, and Platteville Dolomites, Gle
wood Formation, St. Peter Sandstone, Prairie du Chi
Series, Trempealeau Dolomite, Franconia Formati
Ironton Sandstone, and the Galesville Sandstone. The
formations function as an interconnected hydraulic s
tem and occur everywhere in DuPage County.

The Galena, Decorah, and Platteville Dolomites a
considered in this report as one unit, the Galena-Plat
ville Dolomite. Small quantities of water are obtain
from the joints, fractures, and solution cavities in t
Galena-Platteville Dolomite. The casings of wells drill
to the deeper aquifers commonly are seated in t
Galena-Platteville Dolomite.

The Glenwood Formation and St. Peter Sandsto
designated the Glenwood-St. Peter Sandstone, dip fr

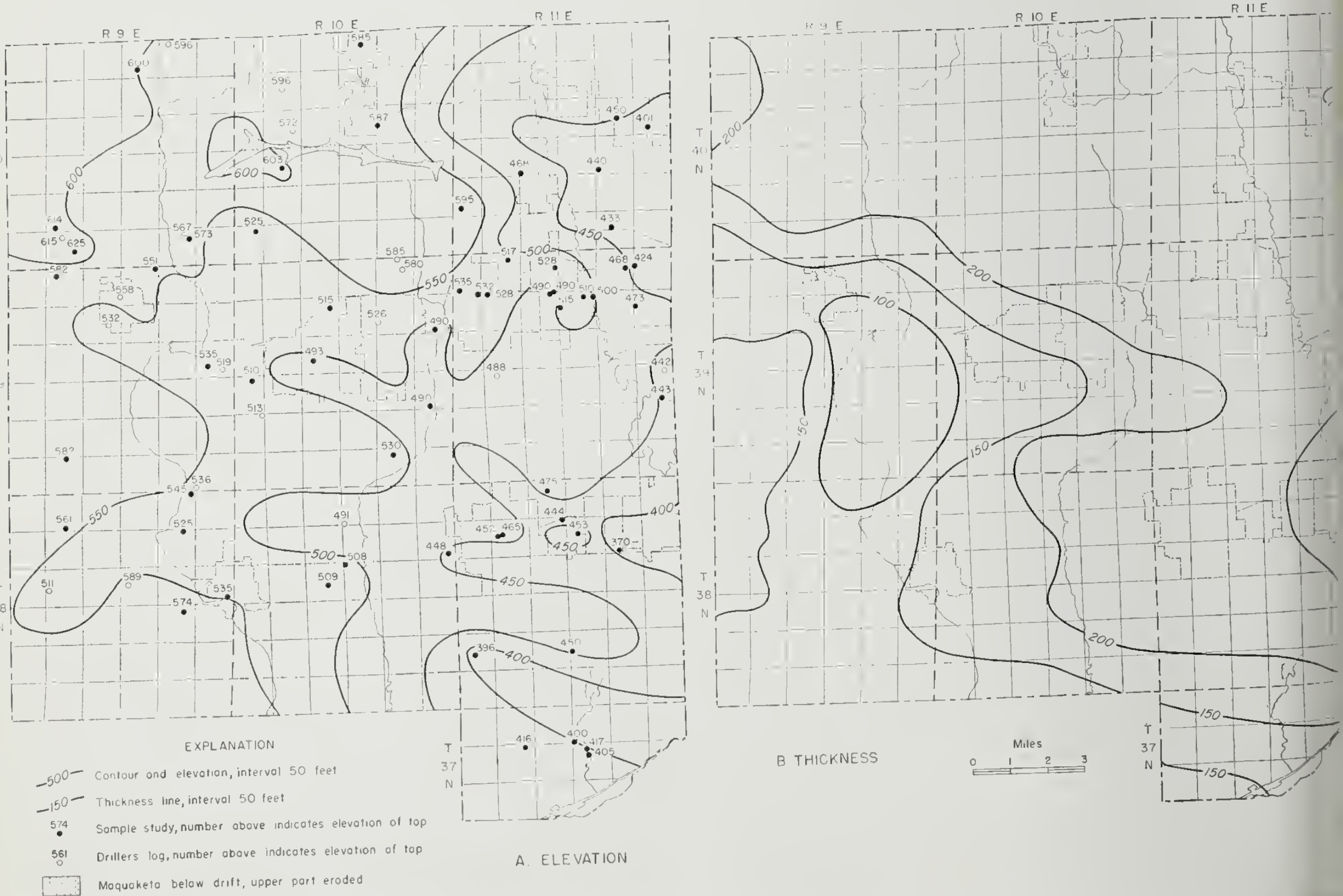
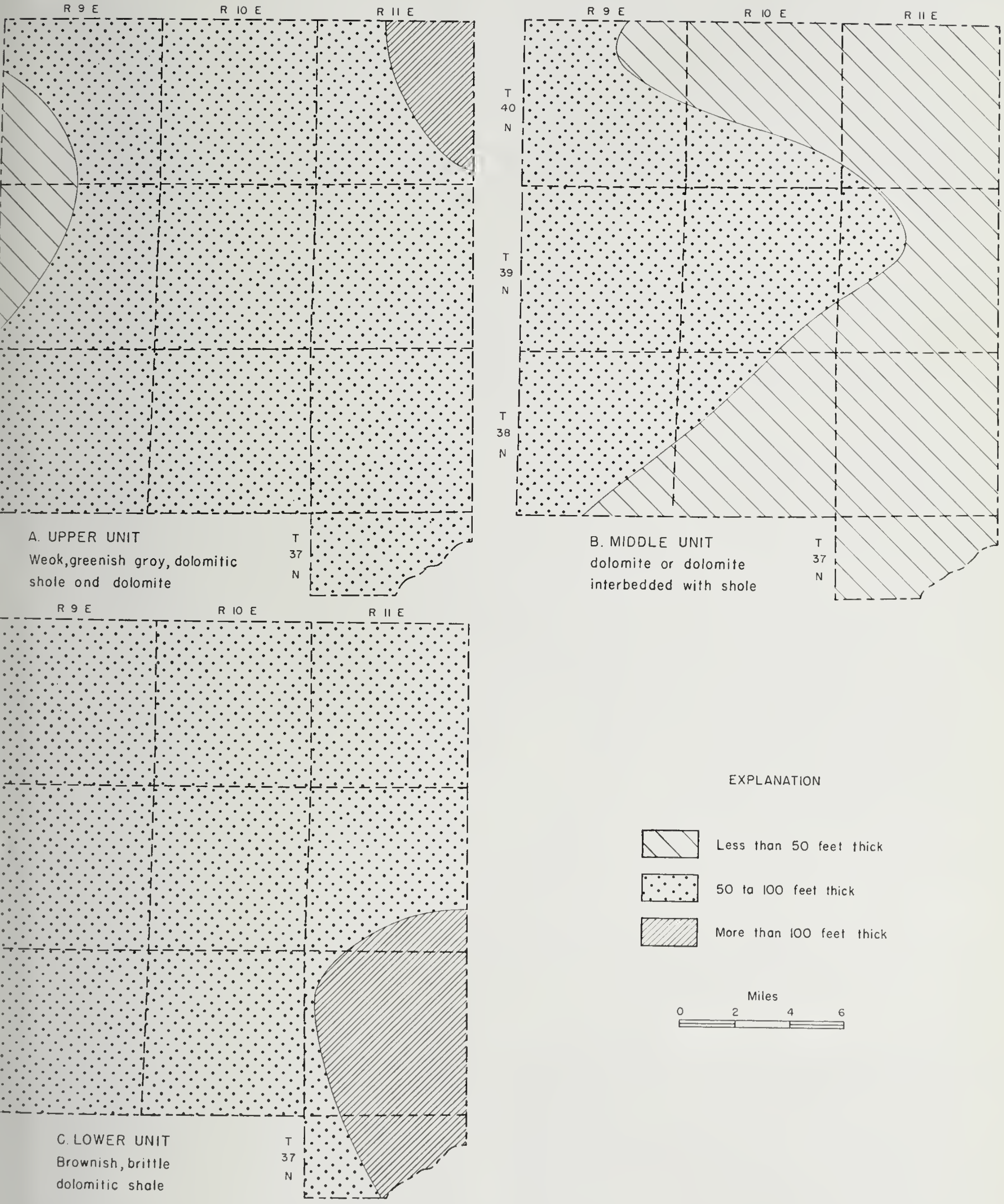

R 9 E
R 10 E
R 11 E
T 40 N
T 39 N
T 38 N
T 37 N
600
550
500
450
400
200
150
100
50
EXPLANATION
500 Contour and elevation, interval 50 feet
150 Thickness line, interval 50 feet
574 Sample study, number above indicates elevation of top
561 Drillers log, number above indicates elevation of top
Maquoketa below drift, upper part eroded
A. ELEVATION
B THICKNESS
Miles
0 1 2 3

Fig. 22. Top elevation (A) and thickness (B) of the Maquoketa Formation (thickness modified from fig. 26, Suter et al., 1959



. Lithologic character and thickness of the upper (A), middle (B), and lower (C) units of the Maquoketa Formation (modified from fig. 25, Suter et al., 1959).

the northwest to the southeast at a rate of about 10 feet to the mile (fig. 24A). Reported thickness of the Glenwood-St. Peter Sandstone beneath DuPage County is commonly about 200 feet. Locally, however, as much as 450 feet of the sandstone is found (fig. 24B). Only five of the wells in DuPage County for which records are available are completed in the Glenwood-St. Peter Sandstone; however, this formation contributes water to wells which penetrate into the deeper Ironton-Galesville Sandstone and Mt. Simon aquifer.

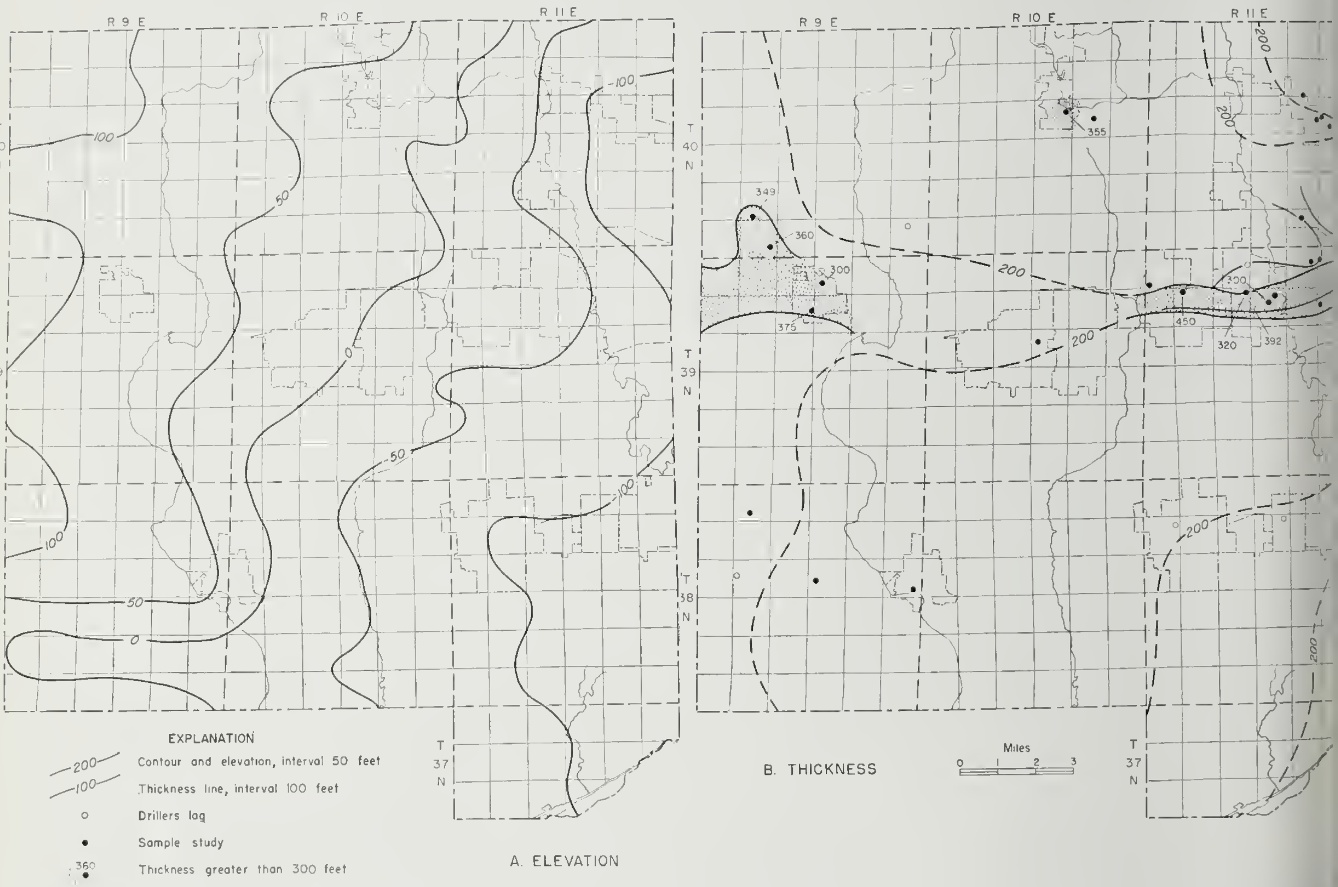


Fig. 24. Top elevation (A) and thickness (B) of the Glenwood-St. Peter Sandstone (modified from fig. 22, Suter et al., 1959

The water-yielding capacity of the Glenwood-St. Peter Sandstone varies with changes in texture, cementation, and thickness. Regionally, the 60 to 80 feet of sandstone which occurs 35 to 200 feet below the top of the formation generally provides most of the water from the Glenwood-St. Peter Sandstone. Unproductive parts are the upper shaly, dolomitic sandstone and the basal shale and conglomerate zone. The drilling and construction of wells in the Glenwood-St. Peter Sandstone is, at places, hindered by the sloughing off of friable sands and the caving of the lower shale or rubble zone. Commonly, the lower shale or rubble zone is cased off wi
a liner.

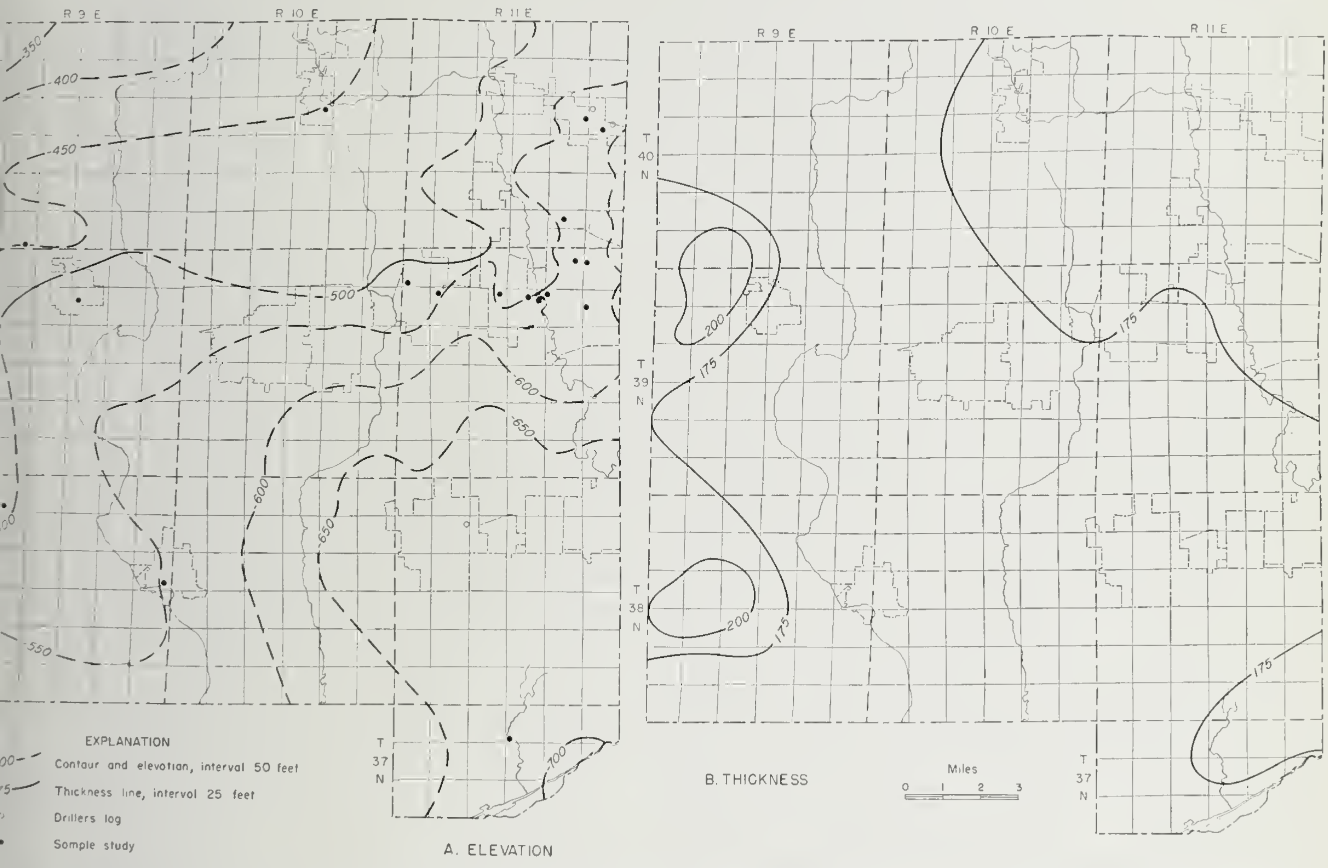
Sandstones and creviced dolomite in the Prairie d
Chien Series, the creviced Trempealeau Dolomite, ar
the sandy parts of the Franconia Formation are cor
monly uncased and contribute ground water to wel
drilled into the Ironton-Galesville Sandstone. Substa
tial percentages of the total yield of the Cambria
Ordovician aquifer are contributed by these units
calculated recently by Walton and Csallany (1962).

The Ironton-Galesville Sandstone is consistently pe
meable and is one of the chief bedrock aquifers in D
Page County. Clean, friable, permeable zones occ
chiefly in the lower 20 to 85 feet of the sandsto
throughout the region, and may be present also in t
upper dolomitic part. The principal water-yielding zo
is the lower part of the Ironton-Galesville Sandsto
(Suter et al., 1959, p. 41).

Records are available for 25 of the deep, high-capac
industrial and municipal wells in the county whi
penetrate the Ironton-Galesville Sandstone. The reliab

ıd consistently high yields of this aquifer are the cipal reasons for its large development in spite of high costs of well construction and maintenance. aquifer has a gentle dip to the southeast of about eet per mile (fig. 25A) and a relatively consistent ness of about 175 to 200 feet in DuPage County 25B).

mmonly, drilling a short distance below the base of ronton-Galesville Sandstone is advisable in order ke full advantage of the favorable water-yielding n the lower part of the aquifer and to insure that ; in the well will not shut off the lower productive 1 (Suter et al., 1959, p. 41). Caving and sand- ng problems in the Ironton-Galesville Sandstone soeiated with the incoherent zones of sand.



25. Top elevation (A) and thickness (B) of the Ironton-Galesville Sandstone (modified from fig. 21, Suter et al., 1959).

fining Beds of the Eau Claire Formation

shale, dolomitic sandstone, and dolomite which up the middle and upper parts of the Eau Claire tion retard ground-water movement between the ian-Ordovician aquifer and the deeper Mt. Simon r. These beds prevent the more highly mineralized waters of the Mt. Simon aquifer from moving into the Ironton-Galesville Sandstone and also are effective in maintaining the head relationships between the two aquifer systems.

Mt. Simon Aquifer

The Mt. Simon aquifer consists of the sandstones of the Mt. Simon Formation and the lower Eau Claire Formation, and is the deepest source of ground water used by wells in DuPage County. Lenses of clean, well-sorted, friable sandstone in the Mt. Simon aquifer yield moderate quantities of water. These lenses are irregularly distributed and are interbedded with micaceous shale and siltstones of low permeability. The top of the Mt. Simon aquifer is reached in drilling in DuPage County at depths of about 1700 to 2000 feet below land surface and the unit dips to the southeast at about 10 feet per mile (fig. 26). Total thickness of the Mt. Simon aquifer is estimated to be about 2000 feet. Regionally, ground water in the Mt. Simon aquifer commonly is too salty for most uses at an elevation of 1300 feet or more below sea level (Suter et al., 1959, p. 41).

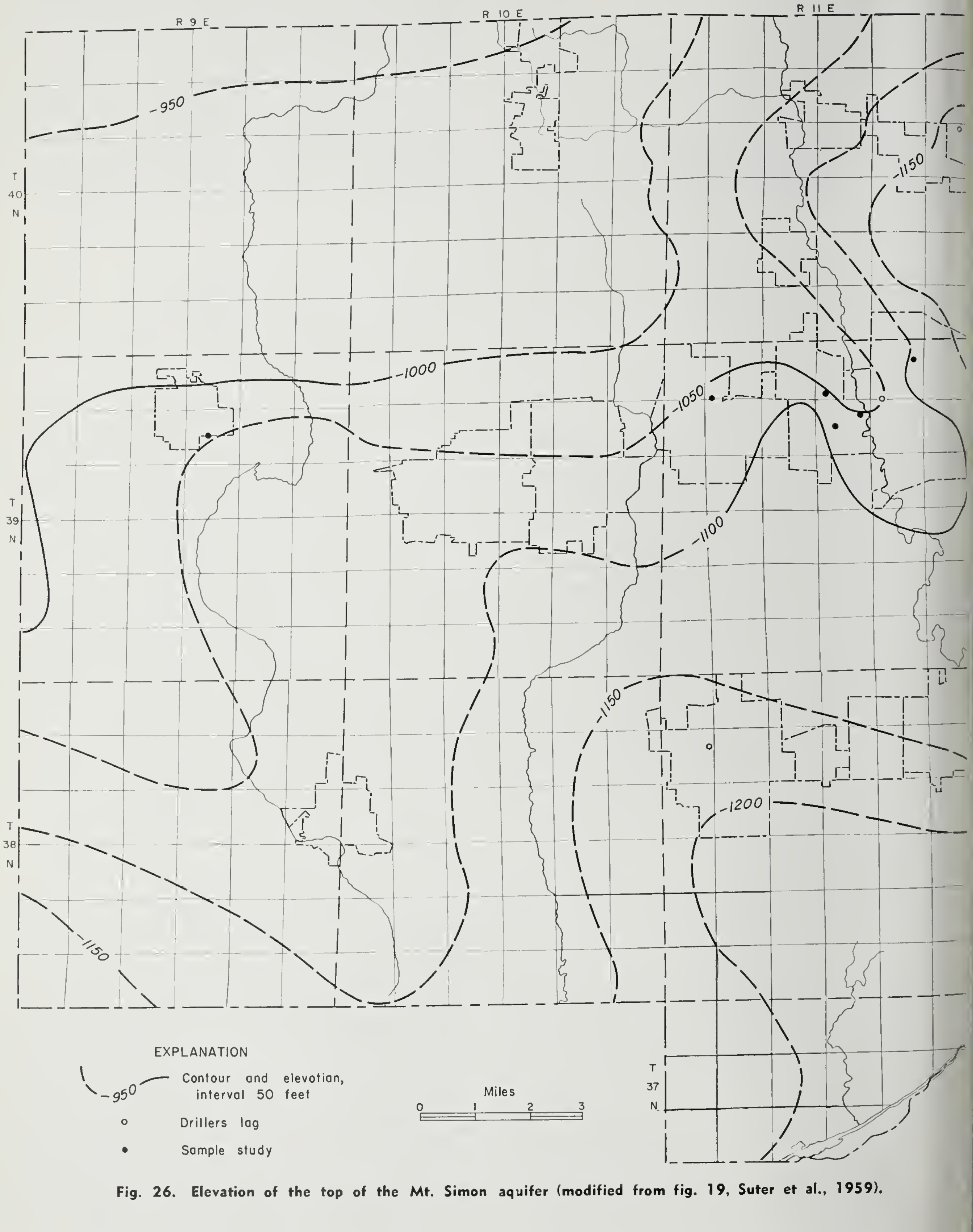


Fig. 26. Elevation of the top of the Mt. Simon aquifer (modified from fig. 19, Suter et al., 1959).

otal pumpage from wells has increased steadily at accelerating rate since the first wells were drilled 1890 as shown in figure 27. During the 70-year od, ..890 to 1960, total pumpage increased from 000 gallons per day (gpd) to 29.3 million gallons day (mgd) at an average rate of about 410,000 gpd year. Pumpage increased very rapidly at an average of 1,300,000 gpd per year during the period 1950 960.

ata in table 7 indicate that of the total water ped from wells in 1960, 68 percent was derived the Silurian dolomite aquifer, 30 percent was ed from the Cambrian-Ordovician and Mt. Simon ers, and 2 percent was derived from the glacial aquifers. In 1960 withdrawals for public water- ly systems amounted to about 68 percent of the pumpage; industrial pumpage was 19 percent of the total; and domestic pumpage was about 13 percent of the total.

ble 7. Distribution of Pumpage from Wells in 1960, Subdivided by Source and Use

	Pumpage from glacial drift aquifers *(mgd)*	Pumpage from Silurian dolomite aquifer *(mgd)*	Pumpage from Cambrian-Ordovician and Mt. Simon aquifers *(mgd)*	Total pumpage *(mgd)*
c	0.13	12.06	7.80	19.99
trial	.02	4.58	1.00	5.60
stic	.38	3.38	......	3.76
'otal	.52	20.02	8.80	29.34

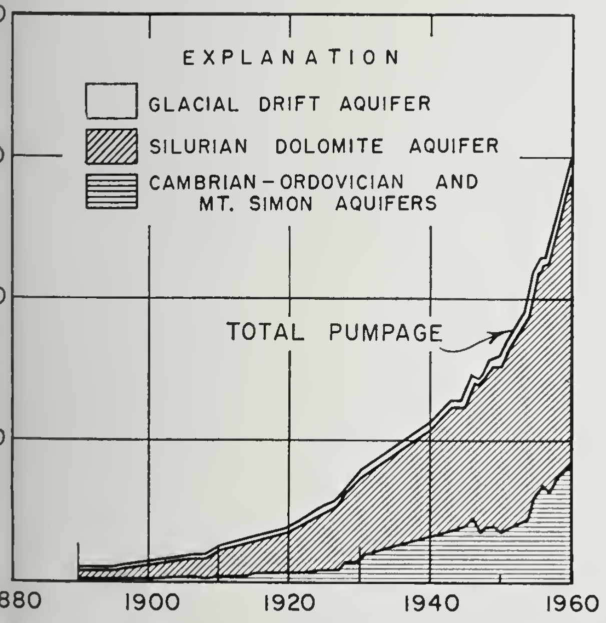


Fig. 27. Pumpage from wells, 1890-1960.

Records of pumpage are fairly complete for the period 1942 to 1960; very few records of pumpage are available for years prior to 1942. The graphs in figure 27 were constructed by piecing together fragments of information on pumpage found in published reports and in the files of the State Water Survey; by making evaluations based on the number of wells, their reported yields, and their time of construction; and by taking into consideration population growth and per capita consumption.

Downward movement of water through the Maquoketa Formation is appreciable under the influence of large differentials in head between shallow deposits and the Cambrian-Ordovician aquifer. Leakage through the Maquoketa Formation within DuPage County was about 1.05 mgd in 1960.

Many deep wells are either uncased or faultily cased in the Mt. Simon and Silurian dolomite aquifers as well as in the Cambrian-Ordovician aquifer. Thus, a large portion of the water pumped from deep wells is obtained from aquifers above and below the Cambrian-Ordovician aquifer. It is estimated that of the 9.0 mgd pumped from deep wells in 1960, 4.9 mgd came from the Cambrian-Ordovician aquifer, 0.2 mgd came from the Silurian dolomite aquifer, and 3.9 mgd came from the Mt. Simon aquifer. The 0.2 mgd obtained from the Silurian dolomite aquifer through deep wells is included in the total pumpage from the Silurian dolomite aquifer in table 7.

Pumpage data are classified in this report according to three main categories: 1) *public,* including municipal, subdivisions, and institutional; 2) *industrial,* including commercial, industrial, golf courses, irrigation, and cemeteries; and 3) *domestic,* including rural farm and rural non-farm.

Most water-supply systems furnish water for several types of use. For example, a public supply commonly includes water used for drinking and other domestic uses, manufacturing processes, and lawn sprinkling. Industrial supplies may also be used in part for drinking and other domestic uses. No attempt has been made to determine the various uses of water within categories. Any water pumped by a municipality is called a public supply, regardless of the use of water.

Municipal and subdivision pumpage data show a gradual change with seasons: the average winter use is about three-fourths of the average summer use. Pumpage from industrial wells generally is more uniform, unless large air-conditioning installations are used, the industry is seasonal, or a change in operation occurs as a result of strikes or vacation shut-downs. The use of water for irrigation is seasonal and varies from year to year depending upon climatic conditions.

The reliability of pumpage data varies greatly. Municipal pumpage nearly always is metered in cities and large villages, but many small villages and subdivisions operate without meters. Only a few of the larger industries meter their supplies. Pumpage data for municipalities and some of the larger industries are systematically recorded. Pumpage from farm wells and individual residential wells is estimated on the basis of detailed use surveys made in a few selected parts of the county considered typical.

Discharge from Wells in Glacial Drift Aquifers

Total pumpage from the glacial drift aquifers was about 0.5 mgd in 1960. More than 70 percent of the pumpage was for domestic use. It is estimated that 10 percent of the rural farm and private residences obtain water from the glacial drift aquifers. In 1960, the city of Wheaton was the only municipality obtaining water from the glacial drift aquifers, and one of its wells is open to both the glacial drift and Silurian dolomite aquifers. For limited periods since 1925, two other municipalities obtained all or part of their water supply from wells finished in the glacial drift aquifers. Public pumpage was 0.13 mgd in 1960, or about 25 percent of the total pumpage from the glacial drift aquifers.

Industrial pumpage is limited to two wells. Both of these wells, drilled after 1956, provide only small amounts of water although their potential yield may be considerably greater. Pumpage for industrial supplies was 0.02 mgd in 1960, or about 5 percent of the total pumpage from the glacial drift aquifers.

Discharge from Wells in Silurian Dolomite Aquifer

Public Supplies

The first public water supplies were developed in 1890 at Hinsdale and Wheaton and had an estimated total pumpage of 180,000 gpd. Public pumpage increased steadily at an accelerating rate, as shown in figure 28, and in 1960 was 12.06 mgd or about 60 percent of the water pumped from the Silurian dolomite aquifer. Pumpage for public supplies has increased at about the same rate as the urban population. Public pumpage in 1960 was about 3.7 times that in 1930 and urban population in 1960 was about 3.1 times that in 1930. The slight leveling off and decreases in public pumpage during the early and mid-1940's were due to restricted expansion of water-supply systems during World War II. In 1960, there were 50 public water supplies obtaining water from the Silurian dolomite aquifer.

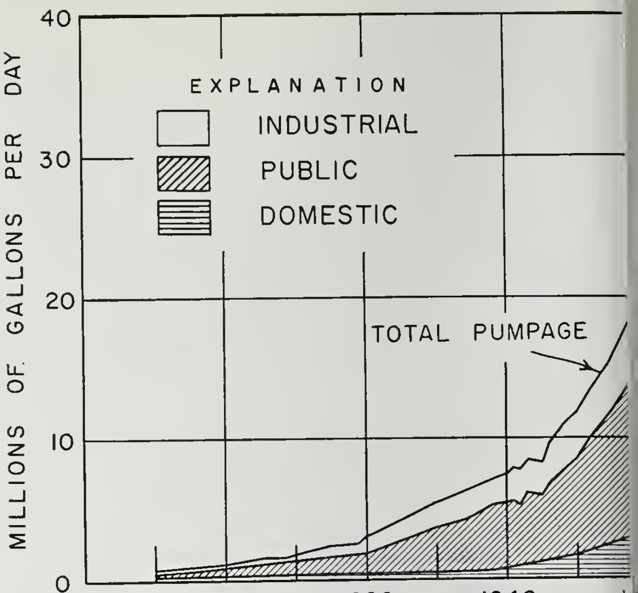


Fig. 28. Pumpage from wells in Silurian dolomite aquifer, 1
1960.

Municipal pumpage amounted to approximately 93 percent of the public pumpage and was 11.2 mg 1960. The remaining 7 percent was nearly evenly tributed between subdivision and institutions. Al the municipalities in the county except one obta all or part of their water supply from wells in Silurian dolomite aquifer.

Although the first subdivision water supply was veloped in 1924, total pumpage for subdivisions a aged less than 100,000 gpd until 1950. More r increases in subdivision pumpage since 1950 reflect population expansion from concentrated urban a of Chicago. Subdivision pumpage in 1960 was a 420,000 gpd.

Most of the institutional pumpage is for public parochial schools outside areas served by municipa subdivision water supply systems. A number of m and restaurants also pump water from the Silu dolomite aquifer. In 1960, institutional pumpage a aged about 480,000 gpd. Since 1940 institutional pu age has increased 2½ times.

Industrial Supplies

The first record of an industrial well in the Silu dolomite aquifer is for a well drilled in 1893 at Downers Grove Golf Club. A deep railroad well dr at West Chicago in 1890 was uncased in and obta water from the Silurian dolomite aquifer. The orig excavation at the rock quarry in Elmhurst started to 1880, and it is assumed that water has been drawn from the quarry since that time. Indus pumpage has increased very slowly in comparison public pumpage, as shown in figure 28, and in as 4.6 mgd or about 23 percent of the water pumped om the Silurian dolomite aquifer.

Data on industrial supplies were obtained from 110 ants. Only a few of the industrial plants meter their mpage. In many cases pumpage was estimated from e number of hours the pump operates and the pump pacity.

omestic Supplies

Domestic pumpage, including rural farm and rural n-farm use, was estimated by considering rural popution as reported by the U. S. Bureau of the Census d per capita use. Based on a survey of selected ral areas within the Chicago region (see Suter et al., 59) the per capita use averages about 50 gpd in Duge County. A survey of domestic wells in a 22-squarele area southwest of Downers Grove and well log ta in the files of the State Geological Survey indicate at on the average about 10 percent of the total dostic pumpage is from the glacial drift aquifers and percent is from the Silurian dolomite aquifer.

Domestic pumpage increased at a rather slow rate at averaged about 20,000 gpd per year prior to 1940 shown in figure 28. During and after World War II rate of increase accelerated and averaged about),000 gpd per year during the period 1940 to 1960. tal domestic pumpage in 1960 was 3.4 mgd or 17 cent of the water withdrawn from the Silurian dolote aquifer. Water for domestic use comes from small lls of low capacity that are widely distributed oughout the county.

stribution and Density of Pumpage

The pumpage from the Silurian dolomite aquifer is uped into 12 centers of pumping based upon areas concentration of use. The location of these centers l the distribution of pumpage in 1960 are shown in figure 29 and table 8, respectively. The greatest quantities of water were withdrawn from wells in pumping centers 5, 7, and 8 which include municipal areas of large population that, except for Lombard, rely entirely on shallow dolomite wells. Pumping center 6, a fourth area of large population, relies primarily on pumpage from deep sandstone wells.

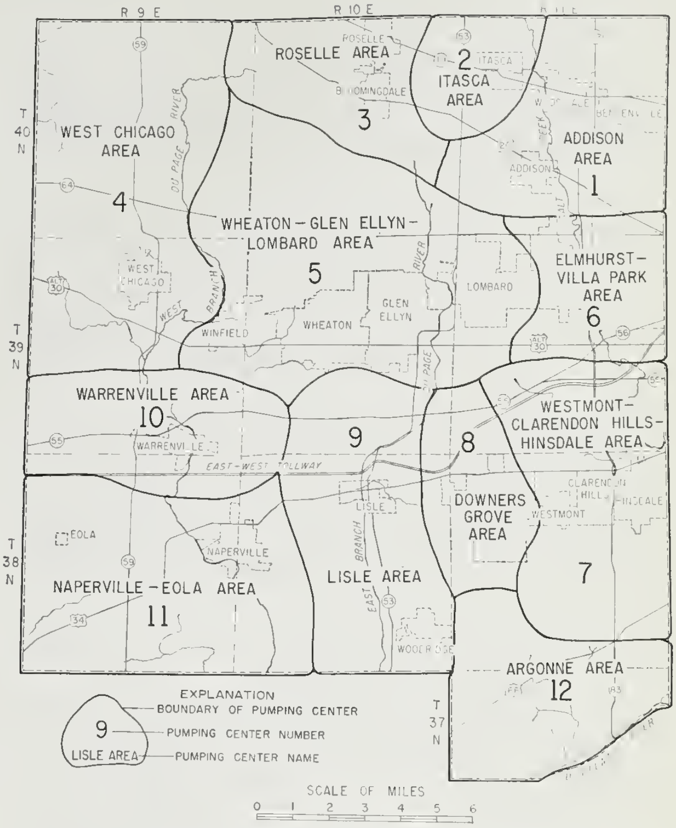


Fig. 29. Location of Silurian dolomite aquifer pumping centers.

able 8. Distribution of Pumpage from Wells in the ilurian Dolomite Aquifer in 1960, Subdivided by Use

umping enter	Public pumpage (*mgd*)	Industrial pumpage (*mgd*)	Domestic pumpage (*mgd*)	Total pumpage (*mgd*)
Addison)	0.55	0.18	0.28	1.01
Itasca)	.20	.11	.09	.40
Roselle)	.28	.06	.22	.56
West Chicago)	.57	.77	.53	1.87
Wheaton-Glen Ellyn-Lombard)	4.05	.22	.53	4.80
Elmhurst-Villa Park)	.51	1.30	.21	2.02
Westmont-Clarendon Hills-Hinsdale)	3.36	.52	.31	4.19
Downers Grove)	1.94	.07	.08	2.09
Lisle)	.36	.10	.32	.78
Warrenville)	.12	.16	.17	.45
Naperville-Eola)	.11	.13	.37	.61
Argonne)	.01	.96	.27	1.24
Total	12.06	4.58	3.38	20.02

In 1910, pumpage from the Silurian dolomite aquifer was largely concentrated in four pumping centers, 4, 5, 6, and 7. Except for the withdrawal of water from the quarry at Elmhurst, early pumpage was from wells in urban centers along railroads leading into Chicago. Withdrawals in pumping center 5 in 1960 were more than 15 times the pumpage in 1910. In all pumping centers except 4, 6, and 11 pumpage in 1960 was more than 10 times the pumpage in 1910. Pumpage from 1890 to 1960 in each of the pumping centers in the Silurian dolomite aquifer in figure 29 is shown in figures 30–33.

Pumpage from the Silurian dolomite aquifer was distributed to the townships within the county, and the average pumpage per square mile (density of pumpage) for each township was computed. Total pumpage and density of pumpage for each township is given in table 9.

The township having the highest density of pumpage is Downers Grove in which are located the municipal

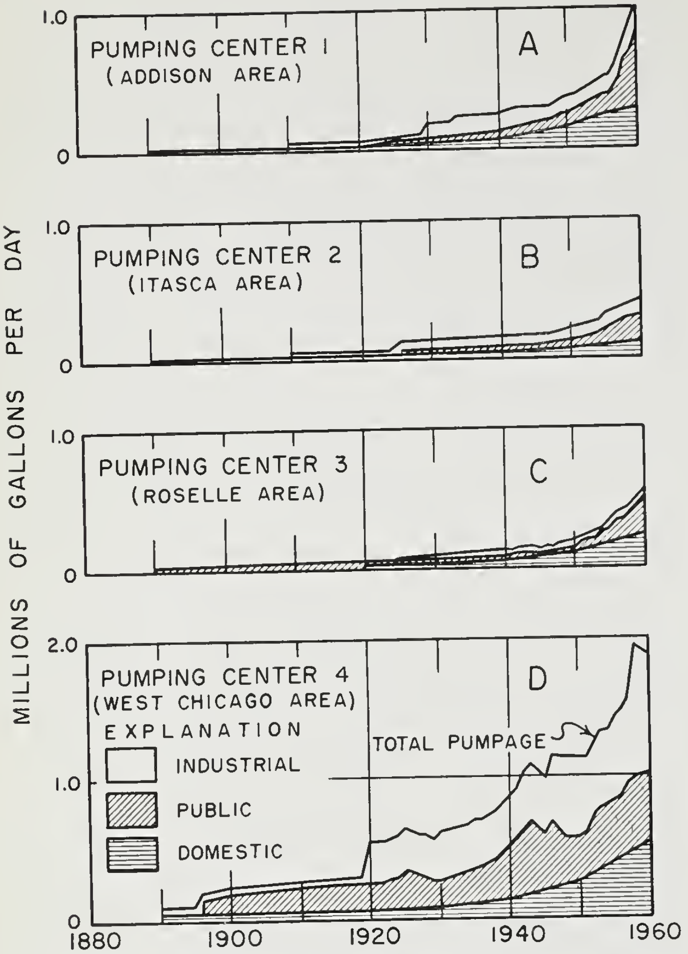


Fig. 30. Pumpage from wells in Silurian dolomite aquifer in pumping centers 1-4, 1890-1960.

wells for Clarendon Hills, Downers Grove, Hinsdale, and Westmont. The density is also high in Milton Township in central DuPage County. The township having the lowest density is Naperville in the southwestern part of the county.

Table 9. Geographic Distribution and Density of Pumpage from Wells in Silurian Dolomite Aquifer in 1960

Location	Total pumpage (*mgd*)	Density of pumpage (*gpd/sq mi*)
Addison (T40N,R11E)	1.34	39,000
Bloomingdale (T40N,R10E)	0.92	27,000
Wayne (T40N,R9E)	0.87	24,000
York (T39N,R11E)	2.97	86,000
Milton (T39N,R10E)	3.98	115,000
Winfield (T39N,R9E)	1.52	42,000
Downers Grove (T38-37N,R11E)	6.86	140,000
Lisle (T38N,R10E)	0.98	27,000
Naperville (T38N,R9E)	0.58	16,000
Total	20.02	

Future Pumpage

Extrapolation of past pumpage records indicates th total pumpage from the Silurian dolomite aquifer m more than double by 1980. The graphs in figure were extrapolated to the year 1980 taking into co sideration past rates of growth of pumpage. It is es mated that total pumpage in 1980 will be in the ord of magnitude of 45 mgd. Withdrawals for public su plies will probably amount to 28 mgd; industrial pum age will probably amount to 10 mgd; and domes pumpage will probably total about 7 mgd. Pumpa increases will probably be great in the Wheaton-Gl Ellyn-Lombard, Westmont-Clarendon Hills-Hinsda Downers Grove, West Chicago, Addison, Roselle, a Lisle areas.

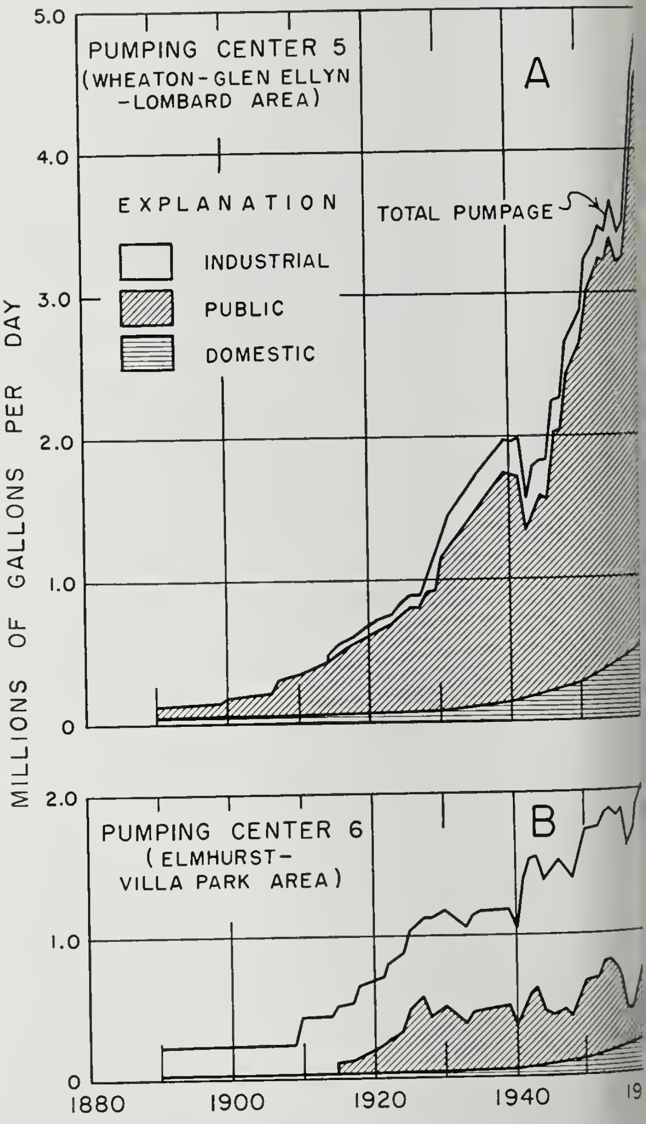


Fig. 31. Pumpage from wells in Silurian dolomite aquifer pumping centers 5 and 6, 1890-1960.

Leakage Through Maquoketa Formation

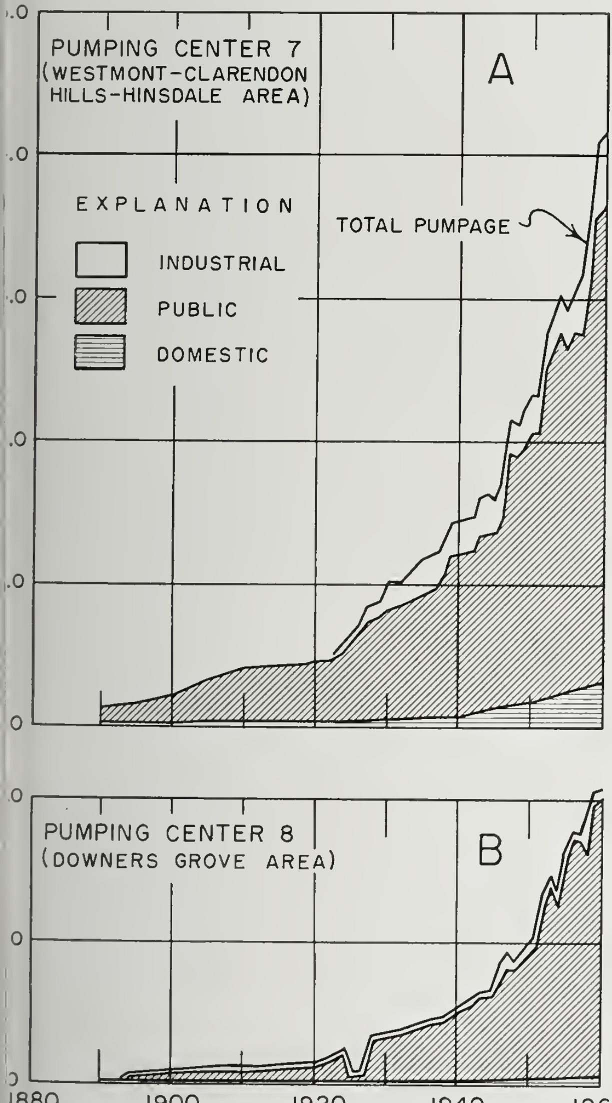
n 1960, the piezometric surface of the Cambrian-
dovician aquifer (see fig. 72, p. 75) was several hun-
d feet below the water table in DuPage County, and
vnward movement of water through the Maquoketa
rmation was appreciable under the influence of large
erentials in head between shallow deposits and the
mbrian-Ordovician aquifer. The quantity of leakage
ough the Maquoketa Formation can be computed
m the following form of Darcy's law:

$$Q_c = (P'/m')\ \Delta h\ A_c \qquad (1)$$

ere:

$)_c$ = leakage through Maquoketa Formation, in gpd

$''$ = vertical permeability of Maquoketa Formation, in gallons per day per square foot (gpd/sq ft)



32. **Pumpage from wells in Silurian dolomite aquifer in pumping centers 7 and 8, 1890-1960.**

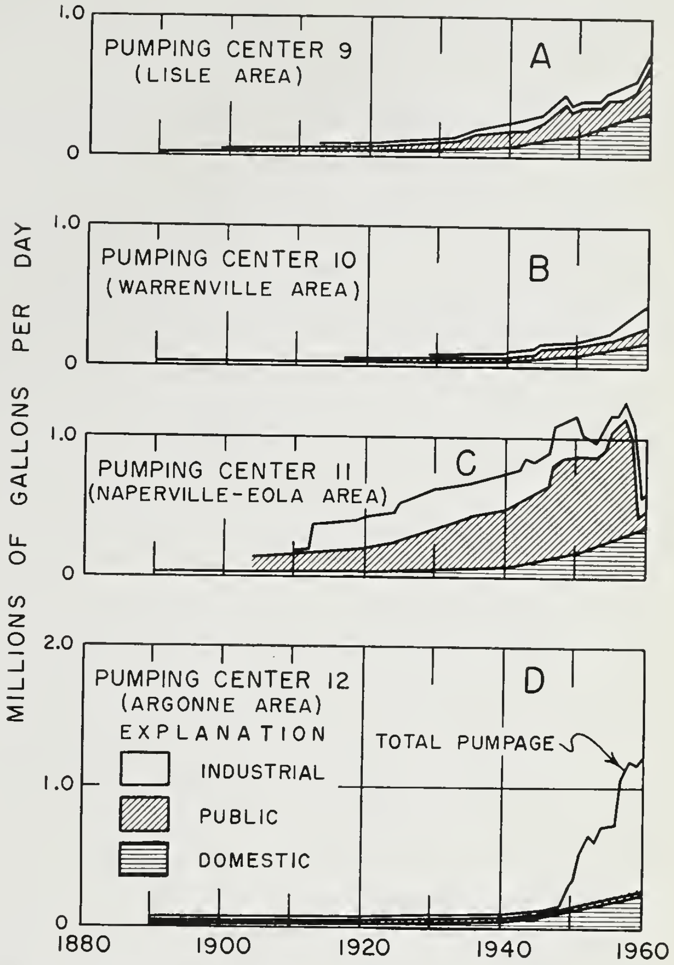


Fig. 33. Pumpage from wells in Silurian dolomite aquifer in pumping centers 9-12, 1890-1960.

m' = thickness of Maquoketa Formation, in feet

A_c = area of Maquoketa Formation through which leakage occurs, in square feet

Δh = difference between the head in the Cambrian-Ordovician aquifer and the head in shallow deposits, in feet

Based on data given by Walton (1960), the average vertical permeability of the Maquoketa Formation in DuPage County is estimated to be about 0.00005 gpd/sq ft. The area of Maquoketa Formation through which leakage occurs in DuPage County is 331 square miles or 9.27×10^9 square feet. The average Δh was determined to be about 400 feet by comparing the piezometric surface maps of water in the Silurian dolomite aquifer (see fig. 52, p. 61) and in the Cambrian-Ordovician aquifer (see fig. 72, p. 75). The average thickness of the Maquoketa Formation is about 175 feet. Substitution of these data in equation 1 indicates that the leakage through the Maquoketa Formation within DuPage County was 1.05 mgd in 1960. Leakage through the

Maquoketa Formation is withdrawal of ground water from the Silurian dolomite aquifer in addition to pumpage.

DISCHARGE FROM WELLS IN CAMBRIAN-ORDOVICIAN AND MT. SIMON AQUIFERS

The first deep sandstone wells penetrating the Cambrian-Ordovician and Mt. Simon aquifers were constructed in 1890 for the village of Hinsdale and the Chicago and Northwestern Railroad at West Chicago. Records indicate that these wells were not tightly sealed through shallow deposits and, therefore, obtained water from both the Silurian dolomite aquifer and the deeper aquifers. Pumpage from deep sandstone wells in 1890 is estimated to have averaged 110,000 gpd. As shown in figure 34, except for short periods, pumpage from the Cambrian-Ordovician and Mt. Simon aquifers increased steadily to 8.8 mgd in 1960.

During the period 1928 to 1931, the rate of increase in pumpage accelerated as deep sandstone wells owned by Lombard and Villa Park were placed in operation. Pumpage reduced from 4.7 mgd in 1946 to 4.0 mgd in 1947 and did not increase appreciably until 1954. During the period 1946 to 1954, there was a rapid conversion to diesel locomotives by railroads thereby reducing their demands for water. Pumpage increased from 4.6 mgd in 1954 to 8.8 mgd in 1960 at an average annual rate of 0.7 mgd.

In 1960, six municipalities, one subdivision, one institution, and six industries obtained all or parts of their supply from the Cambrian-Ordovician and Mt. Simon aquifers. Pumpage for public supplies averaged 7.8 mgd or 89 percent of the total pumpage from deep sandstone wells; industrial pumpage was about 1.0 mgd or 11 percent of the total. Most of the pumpage was from wells in Elmhurst-Villa Park-Lombard a About 1.0 mgd was withdrawn from a deep sandst well at Naperville in 1960.

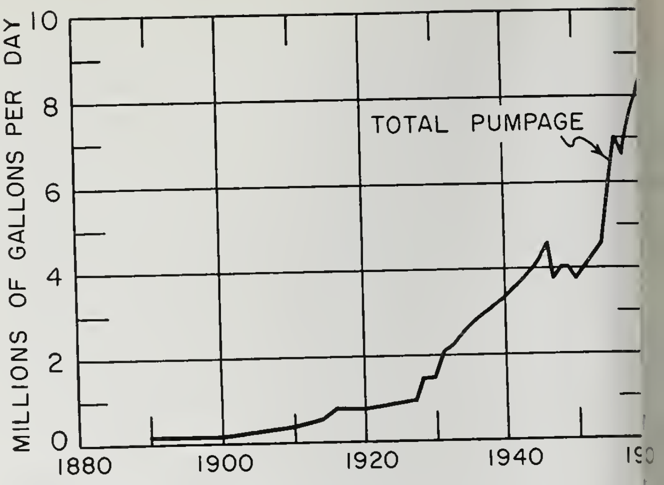


Fig. 34. Pumpage from Cambrian-Ordovician and Mt. Si aquifers, 1890-1960.

Several deep sandstone wells in DuPage County either uncased or faultily cased in the Silurian d mite aquifer and allow leakage. The artesian press of the Cambrian-Ordovician aquifer is lower than t in the Silurian dolomite aquifer. Ground water, th fore, moves downward from the Silurian dolomite a fer through wells that allow leakage. On the basis data in Cooperative Report 1 (1959, p. 62), it is e mated that of the 9.0 mgd pumped from deep sa stone wells in 1960, 0.2 mgd came from the Silu dolomite aquifer. Leakage through wells has decrea during the past several years as a result of recasing wells and more thoroughly sealing new wells to de below the Silurian dolomite aquifer.

HYDROLOGY OF AQUIFERS

Emphasis in this report is placed on the hydrology of the Silurian dolomite aquifer. Little is known concerning the hydrology of the glacial drift aquifers and conclusions reached are inferred mostly from data in Cooperative Report 1. The hydrology of the Cambrian-Ordovician aquifer is described in detail by Suter et al. (1959), Walton (1960), and Walton and Csallany (1962); a summary of published information is presented herein.

SILURIAN DOLOMITE AQUIFER

HYDRAULIC PROPERTIES

The hydraulic properties of aquifers are expressed mathematically by the coefficients of transmissibility T, or permeability P, and storage S. The significant hydraulic property of a confining bed is the vertical p meability P'.

The capacity of a formation to transmit ground w is expressed by the coefficient of transmissibility, wh is defined as the rate of flow of water in gallons day, through a vertical strip of the aquifer one wide and extending the full saturated thickness un a hydraulic gradient of 100 percent (one foot per f at the prevailing temperature of the ground water. coefficient of permeability is defined as the rate of of water in gallons per day, through a cross-secti area of one square foot of the aquifer under a hydra gradient of one foot per foot at the prevailing tem ature of the ground water. The relation of the co cients of transmissibility and permeability is show e equation $T = Pm$, where m is the saturated thickness the aquifer.

The storage properties of an aquifer are expressed the coefficient of storage, which is defined as the lume of water in cubic feet released from or taken into ›rage per square foot of surface area of the aquifer r foot change in the component of head normal to at surface.

The capacity of a confining bed to transmit ground ιter is expressed by its vertical permeability, which defined as the rate of flow of water in gallons per day, rough a horizontal cross-sectional area of one square ›t of the confining bed under a hydraulic gradient of e foot per foot at the prevailing temperature of the ›und water.

The hydraulic properties of a leaky artesian aquifer l its confining bed are often determined by means pumping tests, wherein the effect of pumping a well a known constant rate is measured in the pumped ll and at observation wells penetrating the aquifer. aphs of drawdown versus time after pumping started, l/or of drawdown versus distance from the pumped ll, are used to solve equations which express the rela- n between the coefficients of transmissibility and stor- of the aquifer and the vertical permeability of the ıfining bed, and the lowering of water levels in the inity of a pumped well.

The data collected during pumping tests can be ana- ed by means of the leaky artesian formula (Hantush l Jacob, 1955) which can be expressed by the follow- relation:

$$s = (114.6Q/T) \int_{u}^{\infty} (1/u) \ \exp \ (-u - r^2/4B^2u)\,\mathrm{du}$$

$$s = (114.6Q/T) \ W(u,r/B) \qquad (2)$$

evaluating the integral,

$$\begin{aligned} s = (114.6Q/T) \ 2K_o(r/B) - I_o(r/B) & \left[-Ei\left(-\frac{r^2}{4B^2u}\right)\right] \\ & + \left[\exp\left(-\frac{r^2}{4B^2u}\right)\right] \Big\{ 0.5772 + \ln u + [-Ei(-u)] \\ & - u + u\ [I_o(r/B) - 1]/\frac{r^2}{4B^2} \\ & - u^2 \sum_{n=1}^{\infty} \sum_{m=1}^{n} \frac{(-1)^{n+m}(n-m+1)\,!}{(n+2)\,!^2} \left(\frac{r^2}{4B^2}\right)^m u^{n-m} \Big\} \end{aligned}$$

re:

$$u = 2693r^2S/Tt \qquad (3)$$

ıd

$$r/B = r/\sqrt{T/(P'/m')} \qquad (4)$$

$r/B) =$ modified Bessel function of the second kind and zero order

$r/B) =$ modified Bessel function of the first kind and zero order

$s =$ drawdown in observation well, in ft

$r =$ distance from pumped well to observation well, in ft

$Q =$ discharge, in gpm

$t =$ time after pumping started, in min

$T =$ coefficient of transmissibility, in gpd/ft

$S =$ coefficient of storage of aquifer

$P' =$ coefficient of vertical permeability of confining bed, in gpd/sq ft

$m' =$ thickness of confining bed through which leakage occurs, in ft

One of the assumptions upon which the leaky artesian formula is based is that the aquifer is homogeneous and isotropic. A cursory consideration of the heterogeneous and anisotropic nature of the water-yielding openings of the Silurian dolomite aquifer leads to the conclusion that meaningful values for hydraulic properties cannot be determined with the leaky artesian formula. However, apparent departures from the ideal porous media may not be of serious significance except in the immediate vicinity of a pumped well.

The high yields of many wells and the conformable piezometric surface of the Silurian dolomite aquifer suggest that the dolomite contains numerous interconnected fractures and crevices. Such a network of openings can give a resultant regional effect equivalent to a radially homogeneous aquifer. Because the water flows in fractures and crevices that bring the water directly or by complex interconnection into wells, the flow system assumes at least some of the characteristics of a linear channel in the immediate vicinity of a pumped well where the flow departs from laminar. Thus, the leaky artesian formula may describe drawdown on an areal basis with reasonable accuracy but does not completely describe the drawdown in a pumped well.

PUMPING TESTS

Controlled pumping tests have been conducted by the State Water Survey in the Wheaton area (test 1) and by the U. S. Geological Survey in the Argonne area (test 2) to determine the hydraulic properties of the Silurian dolomite aquifer and its confining beds. The data for these tests are as follows:

Test 1, Wheaton area

A pumping test was made by the State Water Survey on May 2 and 3, 1960. Wells (fig. 35) located within the corporate limits of the city of Wheaton in T39N,R10E were used. The generalized graphic logs of the wells are given in figure 36. The effects of pumping well DUP 39N10E-16.6c1 were measured in the pumped well and in observation well DUP 39N10E-16.6c. Pumping was started at 6:00 p.m. on May 2 and was continued for a period of 24 hours at a constant rate of 830 gpm until 6:00 p.m. on May 3. The closest center of uncontrolled pumping was well 39N10E-15.1b, about 8200 feet east of the pumped well.

Drawdowns in the pumped and observation wells were determined by comparing the extrapolated graphs of water levels measured before pumping started with the graphs of water

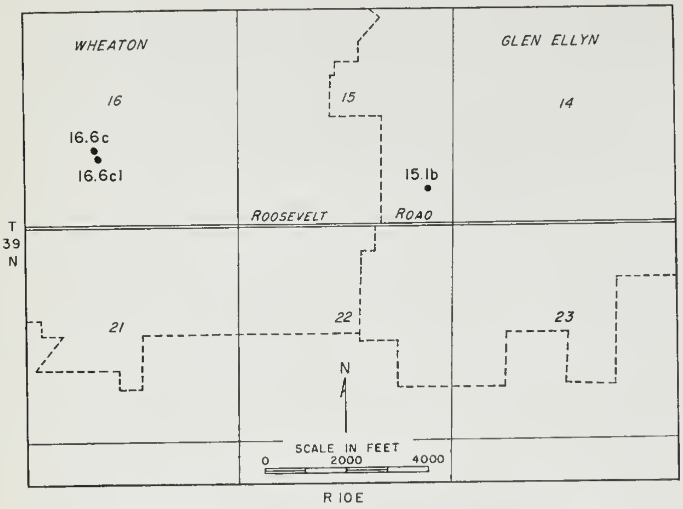


Fig. 35. Location of wells used in pumping test 1.

levels measured during pumping (see fig. 37). Observed drawdowns were adjusted for interference from well 39N10E-15.1b. Adjusted drawdowns in the pumped well were plotted against time on semilogarithmic paper, and adjusted drawdowns in the observation well were plotted against time on logarithmic paper. The time-drawdown field data graph for the observation well is given as an example in figure 38.

As pumping started water levels declined at an initial rate influenced only by the hydraulic properties of the aquifer. After about 15 minutes of pumping, the time-rate of drawdown decreased as vertical leakage became measurable. After about 55 minutes of pumping, water levels were appreciably affected by the operation of the pump in well 39N10E-15.1b as shown in figure 37.

Test 2, Argonne area

A pumping test was made by the U. S. Geological Survey, Ground Water Branch, during the period of August 22 to 24, 1955. Wells (fig. 39) located within the property limits of Argonne National Laboratories in T37N,R11E were used. The generalized graphic logs of the wells are given in figure 40.

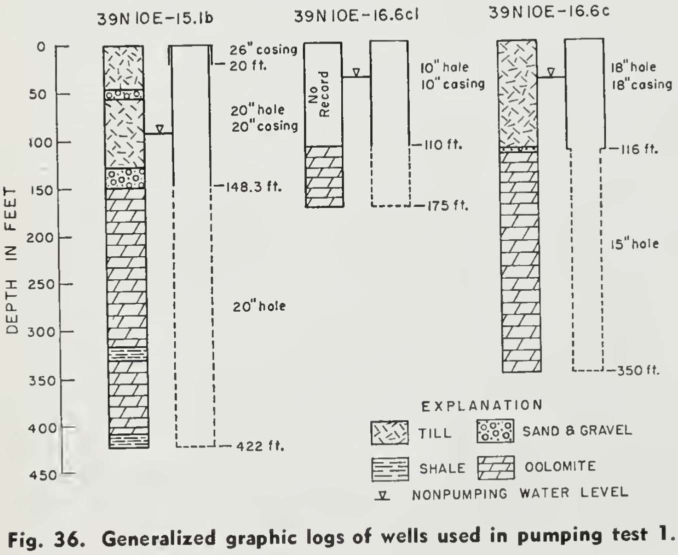


Fig. 36. Generalized graphic logs of wells used in pumping test 1.

Three wells were operated during the test as shown in fig 41. The pumps in wells DUP 37N11E-10.5f, DUP 37N1 10.6g, and DUP 37N11E-3.8a2 were started at 8:04 a 8:11 a.m., and 9:37 a.m., respectively, on August 22. I impossible to isolate the effect of any one pumping w therefore, the drawdown data cannot be used to determine hydraulic properties of the aquifer. During the period 9 a.m. to 10:16 a.m. on August 23, the pumpage from well D 37N11E-3.8a2 was gradually reduced from 920 to 500 g

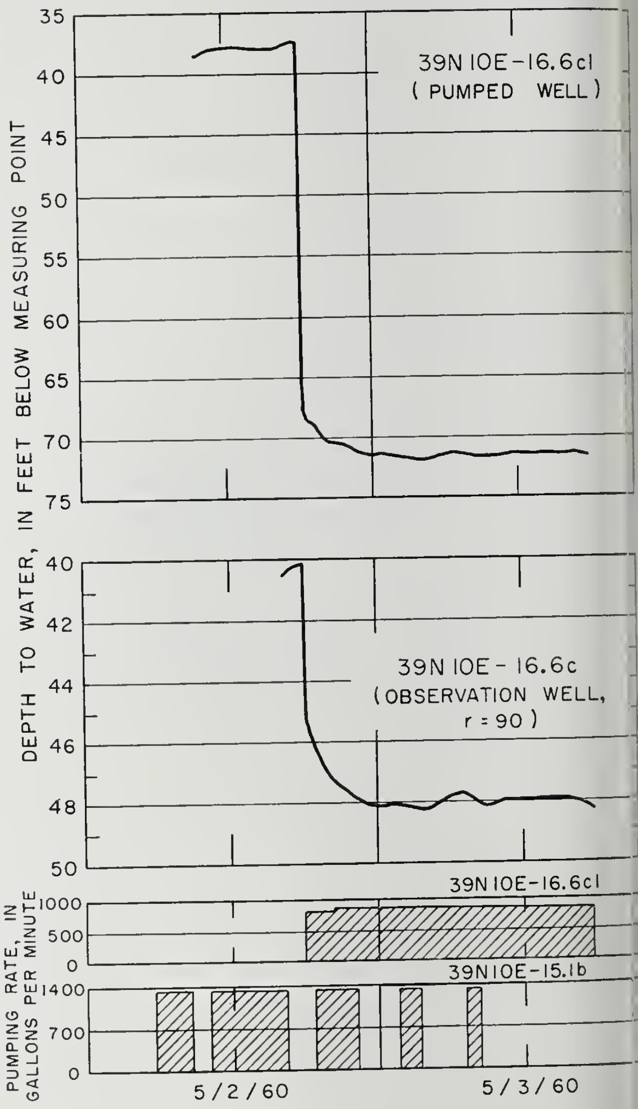
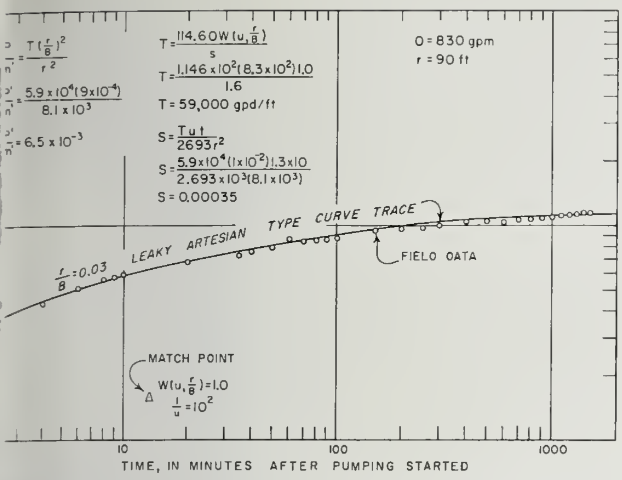


Fig. 37. Water levels and pumpage during pumping test 1

Because the pumpage reduction was gradual and the pump rate was not held constant, the recovery data cannot be an zed.

At 10:00 a.m. on August 23 the pump in well DUP 37N1 10.6g was shut off. Soon afterwards, at 10:25 a.m., pump from well 10.5f was gradually increased from 356 to 419 g Pumpage changes occurred in two wells; therefore, data lected during this period are not suitable for analysis.

On August 24 at 10:00 a.m. the pump in well DUP 37N1 3.8a2 was shut off. Recoveries in observation wells DUP 37N1



38. Time-drawdown graph for well 16.6c, pumping test 1.

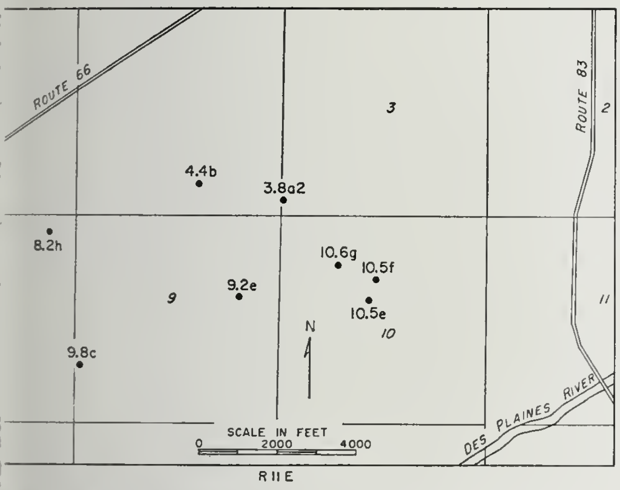
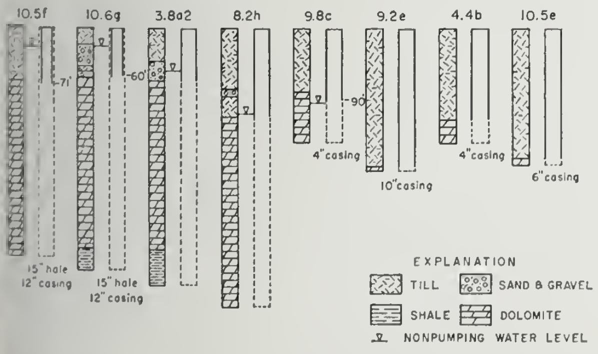


Fig. 39. Location of wells used in pumping test 2.

, DUP 37N11E-4.4b, and DUP 37N11E-10.5e due to reduc- of pumpage in well DUP 37N11E-3.8a2 were plotted on rithmic paper as shown in figure 42.

nfortunately the observation wells penetrate only the upper feet of the dolomite, whereas, as shown in figure 40, well P 37N11E-3.8a2 penetrates more than 200 feet of dolomite.



0. Generalized graphic logs of wells used in pumping test 2.

In addition, the piezometric surface is in both glacial deposits and in dolomite. Thus, the cone of depression expanded into materials having different storage properties during its growth. Because the depth of penetration varies from well to well and the coefficient of storage varied within the cone of depression, the recovery data are equivocal and, as might be expected, the time-drawdown graphs in figure 42 deviate markedly from theory. The hydraulic properties cannot be computed from recovery data.

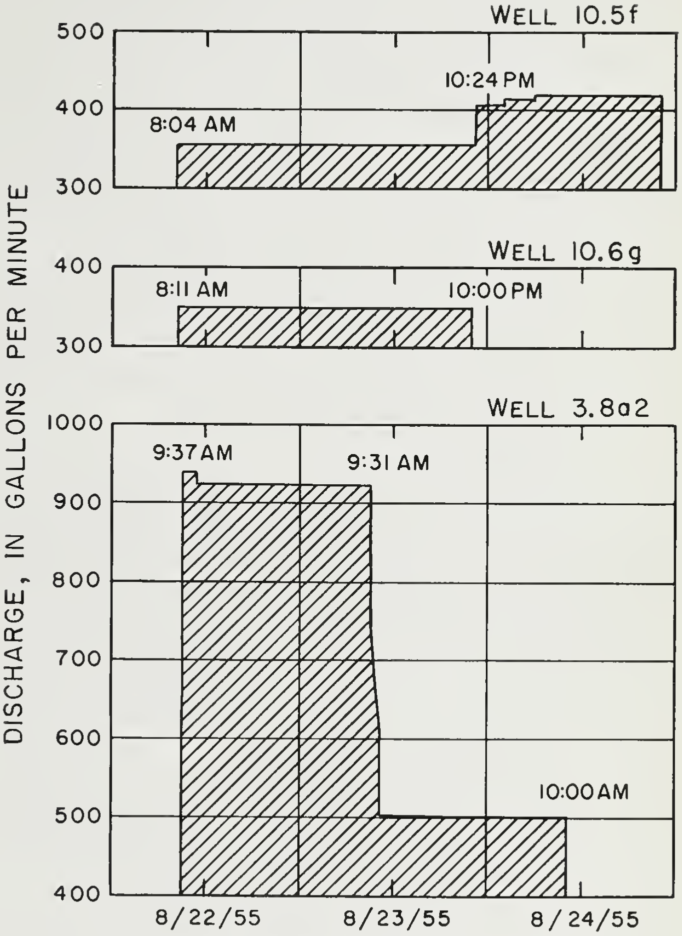


Fig. 41. Pumping conditions during pumping test 2.

The analysis of the interference data for the Wheaton test suggests that the fractures and crevices in the dolomite are interconnected for large distances. A straight line was matched to the time-drawdown graph for the pumped well. The straight-line method described by Cooper and Jacob (1946) and the slope of the time-drawndown graph were used to compute a coefficient of transmissibility of 63,000 gpd/ft. The coefficient of storage cannot be determined from available data because water levels in the pumped well are affected by well loss.

The time-drawdown field data graph for the observation well was superposed on the family of nonsteady-state leaky artesian type curves (Walton, 1960). By in-

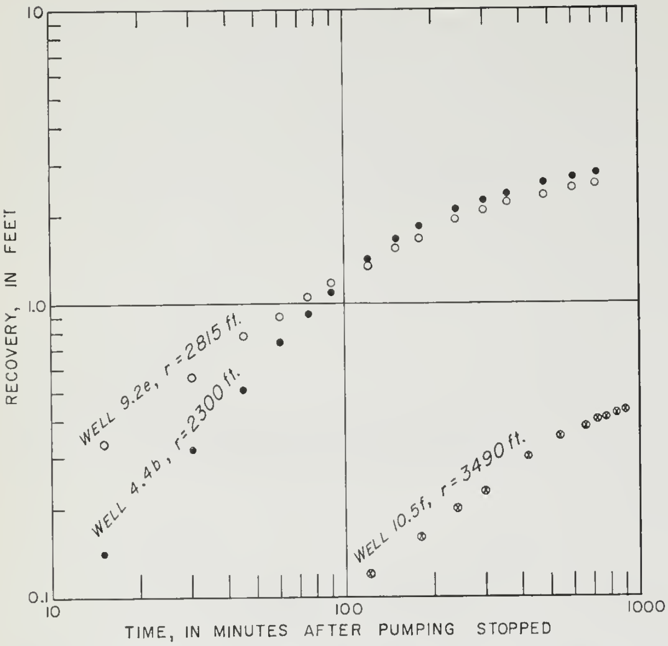


Fig. 42. Time-recovery graphs for wells 9.2e, 4.4b, and 10.5f, pumping test 2.

terpolation, an $(r/B) = 0.03$ type curve was selected as analogous to the time-drawdown field data curve. Equations 2, 3, and 4 were used to compute coefficients of transmissibility and storage of the aquifer, and the leakage coefficient, P'/m' (Hantush, 1956), of the confining bed. Computations are given in figure 38. The average coefficients of transmissibility, storage, and leakage computed from the test results are 61,000 gpd/ft, 0.00035, and 6.5×10^{-3} gpd/cu ft, respectively.

The exact nature and thickness of the confining bed are not known. It is certain, however, that leakage greatly affects the cone of depression created by pumping this well in the Silurian dolomite aquifer.

The drawdown and recovery data obtained during the Argonne test cannot be used to determine the hydraulic properties of the aquifer for reasons given above. By trial and error, it is found that the recoveries in wells DUP 37N11E-9.2e and DUP 37N11E-4.4b (fig. 39) at the end of 700 minutes could be duplicated by using the following properties: $T = 44{,}000$ gpd/ft, $S = 9.0 \text{ x } 10^{-5}$, and $P'/m' = 1.0 \text{ x } 10^{-3}$ gpd/cu ft.

Measurable recovery, about 0.4 foot, was observed in observation well DUP 37N11E-10.5e which is 3490 feet from the pumped well (fig. 39), suggesting that the openings in the Silurian dolomite aquifer are interconnected over considerable distances. It is not unreasonable to believe that if the depth of penetration of all wells was the same, the leaky artesian formula would describe drawdown and recovery on an areal basis with reasonable accuracy.

Specific Capacity Data

The yield of a well may be given in terms of its
cific capacity, which is commonly expressed as the
in gallons per minute per foot of drawdown (gpm
for a stated pumping period and rate. The theore
specific capacity Q/s of a well can be written as

$$Q/s = T/[114.6\ W(u,r/B)]$$

The specific capacity is influenced (see equations
and 4) by the hydraulic properties of the aquifer
confining bed, the thickness of the confining bed,
radius of the well, and the pumping period. From e
tion 5 the theoretical specific capacity of a well i
rectly proportional to T and inversely proportion
log T. The relationship between the theoretical sp
capacity of a well and the coefficient of transmissib
is shown in figure 43. A pumping period of 8 hou

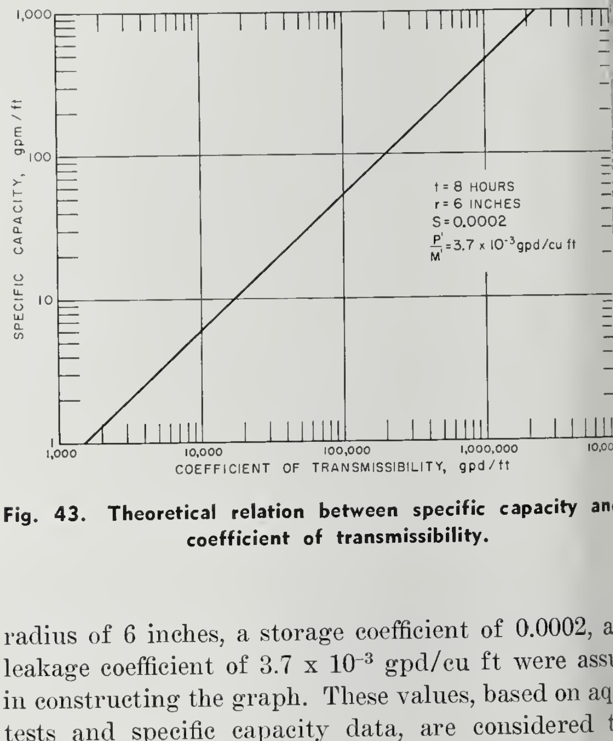


Fig. 43. Theoretical relation between specific capacity an coefficient of transmissibility.

radius of 6 inches, a storage coefficient of 0.0002, a
leakage coefficient of $3.7 \text{ x } 10^{-3}$ gpd/cu ft were ass
in constructing the graph. These values, based on aq
tests and specific capacity data, are considered
average for the county.

The theoretical specific capacity considers only
head loss (aquifer loss) due to the laminar flow of
in the aquifer towards the well and ignores the
loss (well loss) resulting from the turbulent flo
water in the immediate vicinity of the well, throug
well wall, and in the well bore. The specific capa
of Silurian dolomite aquifer wells in DuPage C
decrease with an increase in the pumping rate, in
ing that well loss is appreciable. Taking both a
and well losses into consideration, the actual speci
pacity Q/s_a is given by the following equation:

$$Q/s_a = Q/(s + s_w) \qquad (6)$$

ere:

s = aquifer loss described by equation 2

$_w$ = well loss

Vell loss may be represented approximately by the owing equation (Jacob, 1946):

$$s_w = CQ^2 \qquad (7)$$

ere:

C = empirical well loss in sec^2/ft^5

Q = rate of pumping in cubic feet per second (cfs)

he value of C may be computed from the data col- ed during a "step-drawdown" test, in which the well perated during three successive periods of equal du- on at constant fractions of full capacity, by using or both of the following equations (see Jacob, 1946):

steps 1 and 2

$$C = \frac{(\Delta s_2/\Delta Q_2) - (\Delta s_1/\Delta Q_1)}{\Delta Q_1 + \Delta Q_2} \qquad (8)$$

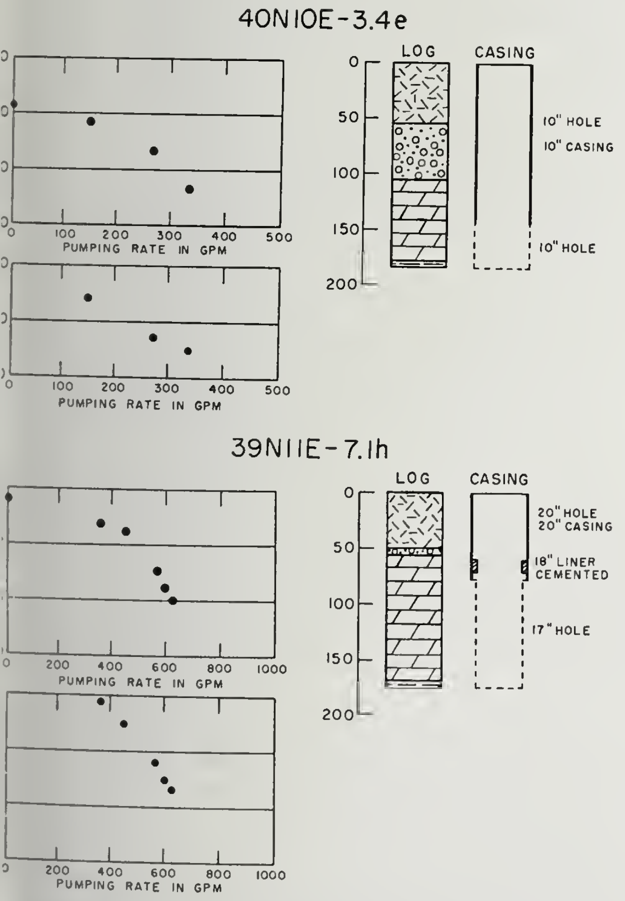
steps 3 and 4

$$C = \frac{(\Delta s_3/\Delta Q_3) - (\Delta s_2/\Delta Q_2)}{\Delta Q_2 + \Delta Q_3} \qquad (9)$$

Δs terms represent increments of drawdown produced by each increase (ΔQ) in the rate of pumping. The dimensions of Δs and ΔQ are feet and cubic feet per second respectively.

If step-drawdown test data are available the well-loss constant and the well loss can be estimated. The aquifer loss is then computed by subtracting the well loss from the observed drawdown. The coefficient of transmissibility of the Silurian dolomite aquifer may be estimated with the graph in figure 43 and the theoretical specific capacity based on the aquifer loss.

Step-drawdown test data are available for several wells in DuPage County. Data for the tests made on nine selected wells are presented graphically in figures 44–47. Analysis of available data indicates that the well-loss constant C is a function of 1) the specific capacity and therefore the hydraulic properties of the dolomite, and 2) the position of the pumping level in relation to the top of the Silurian dolomite aquifer. High values of C are computed for wells having low specific capacities and low values of C are computed for wells having high



44. Step-drawdown test data and construction features of wells 40N10E-3.4e and 39N11E-7.1h.

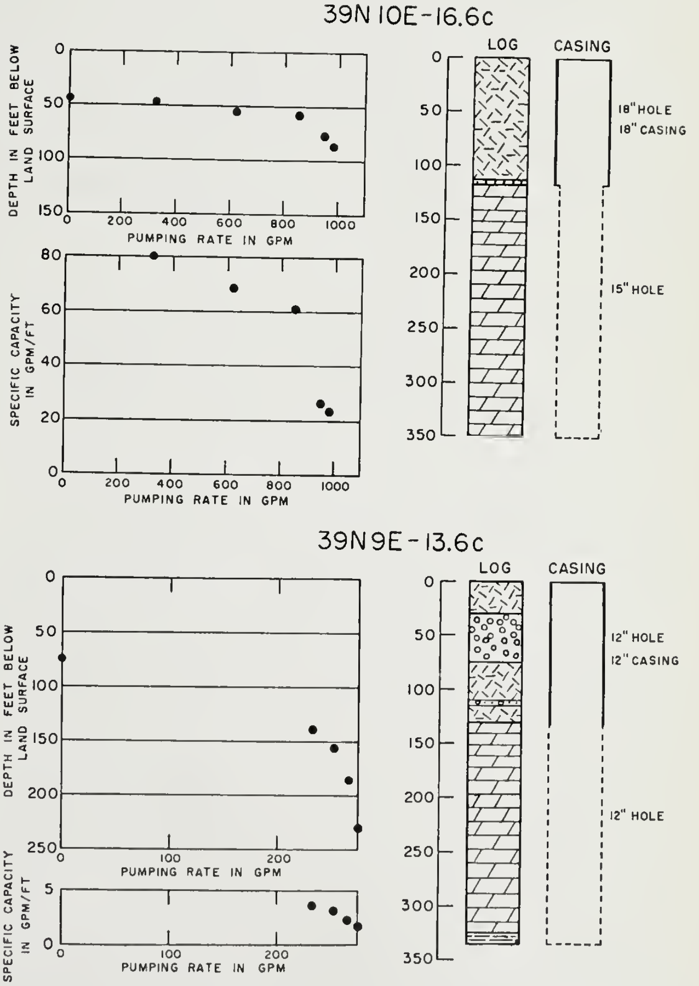


Fig. 45. Step-drawdown test data and construction features of wells 39N10E-16.6c and 39N9E-13.6c.

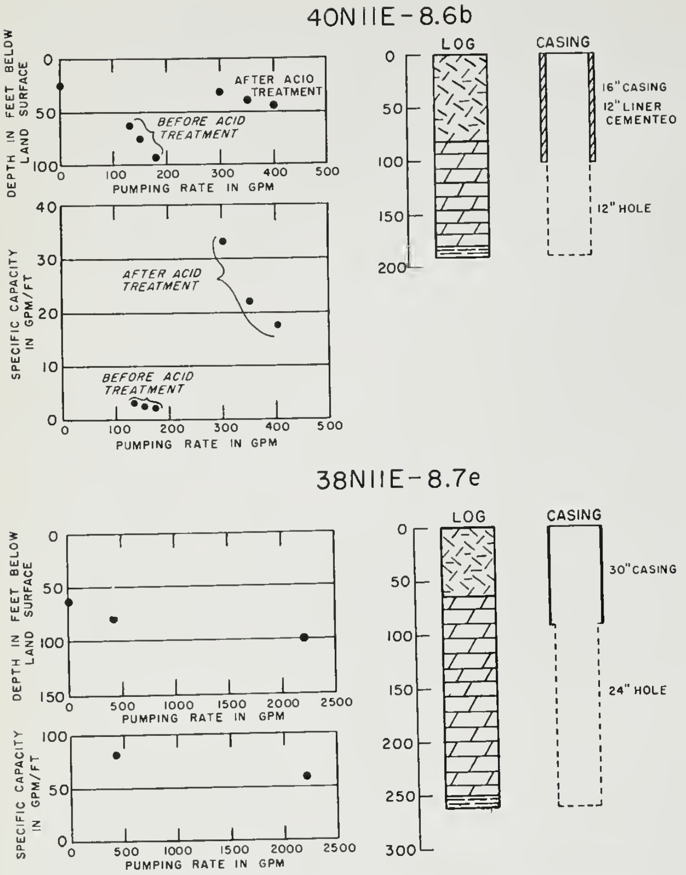


Fig. 46. Step-drawdown test data and construction features of wells 40N11E-8.6b and 38N11E-8.7e.

specific capacities. Apparently turbulence and therefore well loss increases as the coefficient of transmissibility of the aquifer decreases. The coefficient of transmissibility becomes smaller with a decrease in the size and/or number of interconnected openings in the dolomite.

The well-loss constant increases greatly when water levels are lowered below the top of the Silurian dolomite aquifer. As the pumping level declines below the top of the aquifer, maximum contribution from openings in the upper part of the dolomite above the pumping level is attained and future increases in pumpage are obtained from the openings below the pumping level. A greater burden is placed upon lower openings and well loss is greatly increased.

Graphs were prepared showing the relations between actual specific capacity and the well-loss constant for the two cases, when the pumping level is above the top of the aquifer (fig. 48) and when the pumping level is below the top of the aquifer (fig. 49).

Available specific capacity data are given in Appendix C. Most of these data were collected during well-production tests made by personnel of the State Water Survey. Well-loss constants were estimated for each well

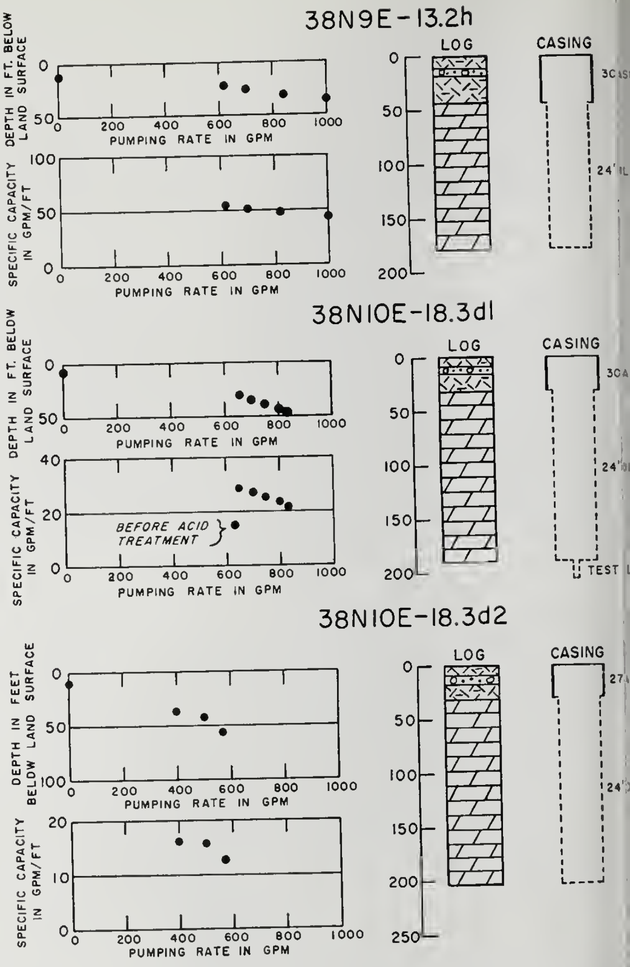
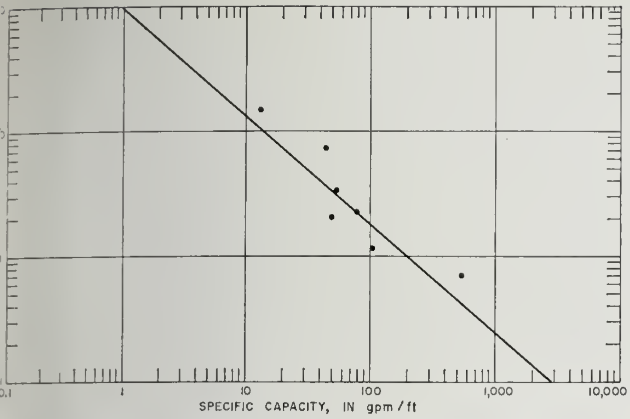


Fig. 47. Step-drawdown test data and construction featur wells 38N9E-13.2h, 38N10E-18.3d1, and 38N10E-18.3

based on actual specific capacities, water-level data, figures 48 and 49. Well losses were calculated with mated well-loss constants and equation 7 and were tracted from observed drawdowns to determine aq losses. Theoretical specific capacities were then puted for a pumping period of 8 hours and a radi 6 inches based on aquifer losses and equation 2. T retical specific capacities and the graph of the theore relationship between specific capacity and the coeffi of transmissibility (fig. 43) were used to estimate average coefficient of transmissibility of the Silurian omite aquifer within the cones of depression of pr tion wells.

Estimated coefficients of transmissibilities are in Appendix C. No great accuracy is implied fo estimated coefficients of transmissibilities because are based on an average coefficient of storage and ve permeability and on estimated well-loss constants addition, geohydrologic boundaries were not consi in the analysis of specific capacity data. The da Appendix C can only be considered rough appro



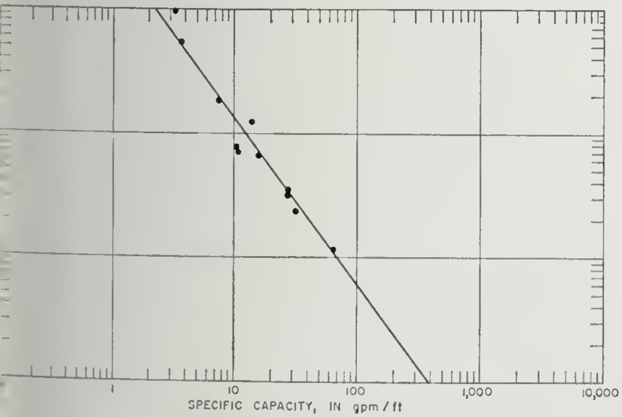
. 48. Well-loss constant versus specific capacity, pumping levels are above the top of the Silurian dolomite aquifer.

ns of this hydraulic property of the dolomite. How-r, the coefficient of transmissibility estimated from ecific capacity data for wells at Wheaton agree closely h the coefficient of transmissibility computed from mping test data, indicating that the estimated coef-ents of transmissibility are meaningful.

Actual specific capacities and specific capacities ad-ted for well loss and to a common pumping period l radius (Appendix C) were divided by depths of netration to obtain actual and adjusted specific ca-ities per foot of penetration.

Many wells penetrate only rocks of the Niagaran (N) ies; some wells penetrate rocks of both the Niagaran l Alexandrian (A) Series; other wells penetrate rocks both the Niagaran and Alexandrian Series and the quoketa (M) Formation. The total depth of penetra-n of wells and the depth of penetration of wells into h unit were determined by studies of well logs and nples of drill cuttings and are given in Appendix C.

Wells were segregated into three categories, N, N + A, l N + A + M, depending upon the units penetrated by the wells. Specific capacities per foot of penetration for wells in each of the three categories were tabulated in order of magnitude, and frequencies were computed by the Kimball (1946) method. Values of specific capacity per foot of penetration were then plotted against percent of wells on logarithmic probability paper as shown in figure 50.



49. Well-loss constant versus specific capacity, pumping levels are below the top of the Silurian dolomite aquifer.

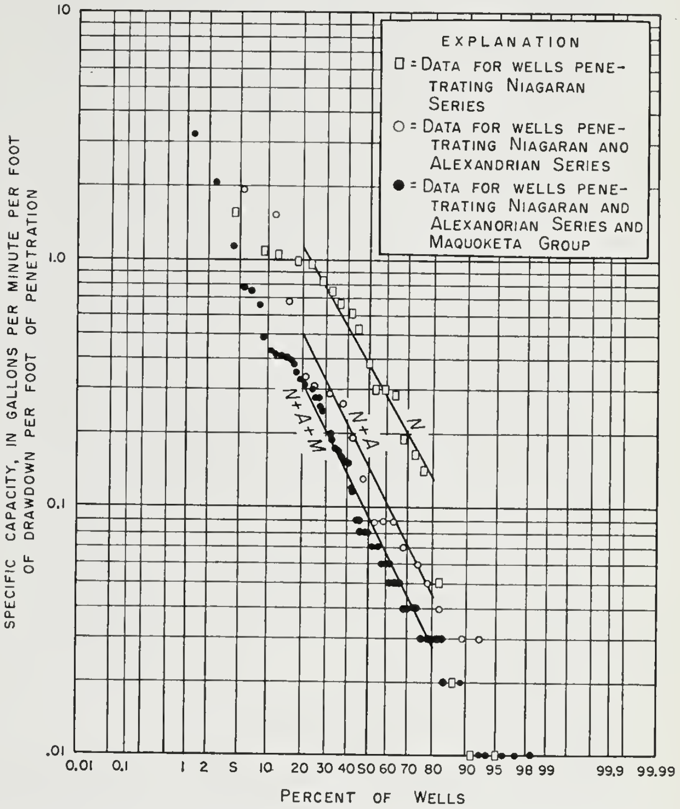


Fig. 50. Specific capacity frequency graphs for dolomite wells.

Specific capacities per foot of penetration decrease as the number of units penetrated increase indicating that where they overlie one another the Niagaran and Alexandrian Series are more productive than the Maquoketa Formation, and the Niagaran Series is more productive than the Alexandrian Series. Sufficient data are not available to evaluate variations of specific capacities per foot of penetration within each of the units.

The unit frequency graphs in figure 51 were constructed with figure 50 by the process of subtraction taking into consideration uneven distribution of wells in the three categories. The slope of a unit frequency graph varies with the inconsistency of production, a steeper line indicating a larger range in productivity. Figure 51 indicates that the Maquoketa Formation is much less consistent in production than both the Niagaran and Alexandrian Series and the productivity of the Alex-

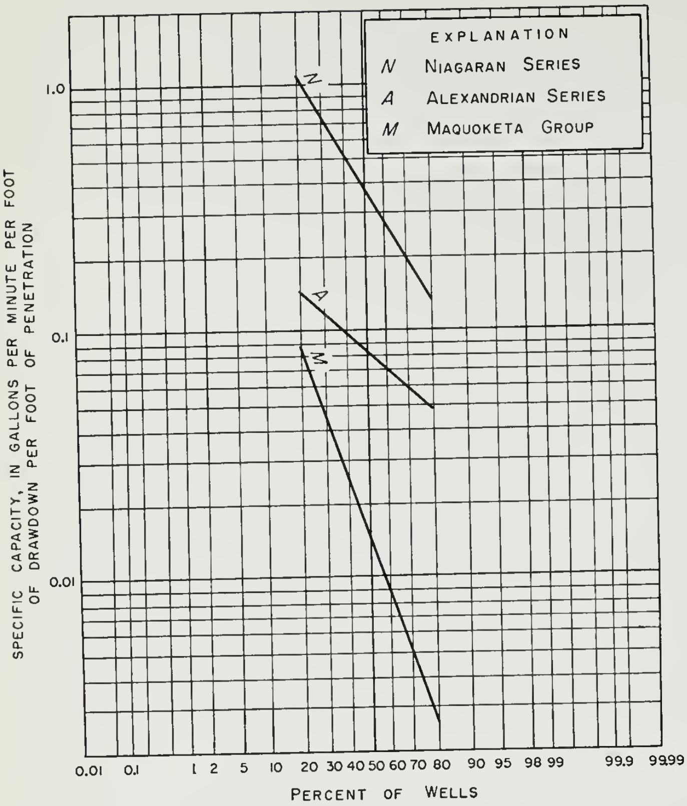


Fig. 51. Specific capacity frequency graphs for the units penetrated by wells.

andrian Series is more consistent than the productivity of the other units.

Piezometric Surface

In order to determine areas of recharge and discharge and directions of ground-water movement in the Silurian dolomite aquifer, a piezometric surface map was made (fig. 52). Data on nonpumping levels in Appendix D were used to prepare the map. A piezometric surface is an imaginary surface to which water will rise in artesian wells. Lines of equal elevation representing lines of equal pressure on the piezometric surface are called isopiestic lines. The direction of ground-water movement is at right angles to isopiestic lines.

The piezometric surface map in figure 52 is a composite of water levels, and no distinction is made between ground water under artesian or water-table conditions. The piezometric surface map represents the elevation to which water will rise in a well completed in the Silurian dolomite aquifer and does not usually coincide with the position of the water table in shallow glacial drift deposits.

As shown by figure 52, ground water in DuPage County moves in all directions from uplands toward streams and toward well fields. In areas unaffected by heavy pumping, the piezometric surface conforms generally to the configuration of the land surface. T relief of the piezometric surface is much less than t relief of the land surface except in the immedia vicinity of well fields.

Valleys in the piezometric surface correspond wi most of the West Branch DuPage River valley and t lower and upper reaches of East Branch DuPage Rive The flow of these streams between periods of precip tation is maintained by ground-water runoff. Pumpi in the Glen Ellyn, Lisle, Clarendon Hills, Hinsdale, a Elmhurst areas has probably reduced natural dischar of ground water to East Branch and to Salt Creek. some areas along East Branch and Salt Creek the piez metric surface is below the water surfaces of the strea and small amounts of surface water probably percola through the stream bed and eventually into the Siluri dolomite aquifer.

Heavy concentrated pumpage from wells has p duced cones of depression in many parts of the coun The piezometric surface map shows well-defined cones depression around the communities of Downers Gro West Chicago, Lisle, and Glen Ellyn. A pronounc ground-water trough extends through Hinsdale, Clar don Hills, and Westmont and a deep, local cone depression is centered at the stone quarry in Elmhu Pumpage within the Argonne National Laboratory l distorted contours on the piezometric surface, and sma local cones of depression occur around numerous ar of pumping in the county.

Flow lines, paths followed by particles of water they move through the aquifer in the direction decreasing head, were drawn at right angles to piezometric surface contours. The areas of influe of production wells in the county were outlined shown in figure 53 by analysis of flow lines. In 1 about 47 percent of the piezometric surface in DuP County was influenced by withdrawals from wells the Silurian dolomite aquifer.

The glacial drift overlying the dolomite permits tical movement of ground water from the water ta to the dolomite. Vertical movement and therefore charge to the dolomite occurs in areas where the pi metric surface is below the water table. A study of piezometric surface of the Silurian dolomite aqui (fig. 52), the areas influenced by withdrawal from w in the Silurian dolomite aquifer (fig. 53), and wa level data for shallow water-table wells indicate t recharge is occurring in most, if not all, upland a and some lowland areas within the county.

The average slope of the piezometric surface areas unaffected by pumpage is about 5 feet per m Gradients are steeper and exceed 20 feet per mile i and within cones of depression.

The general pattern of flow of water in the dolo

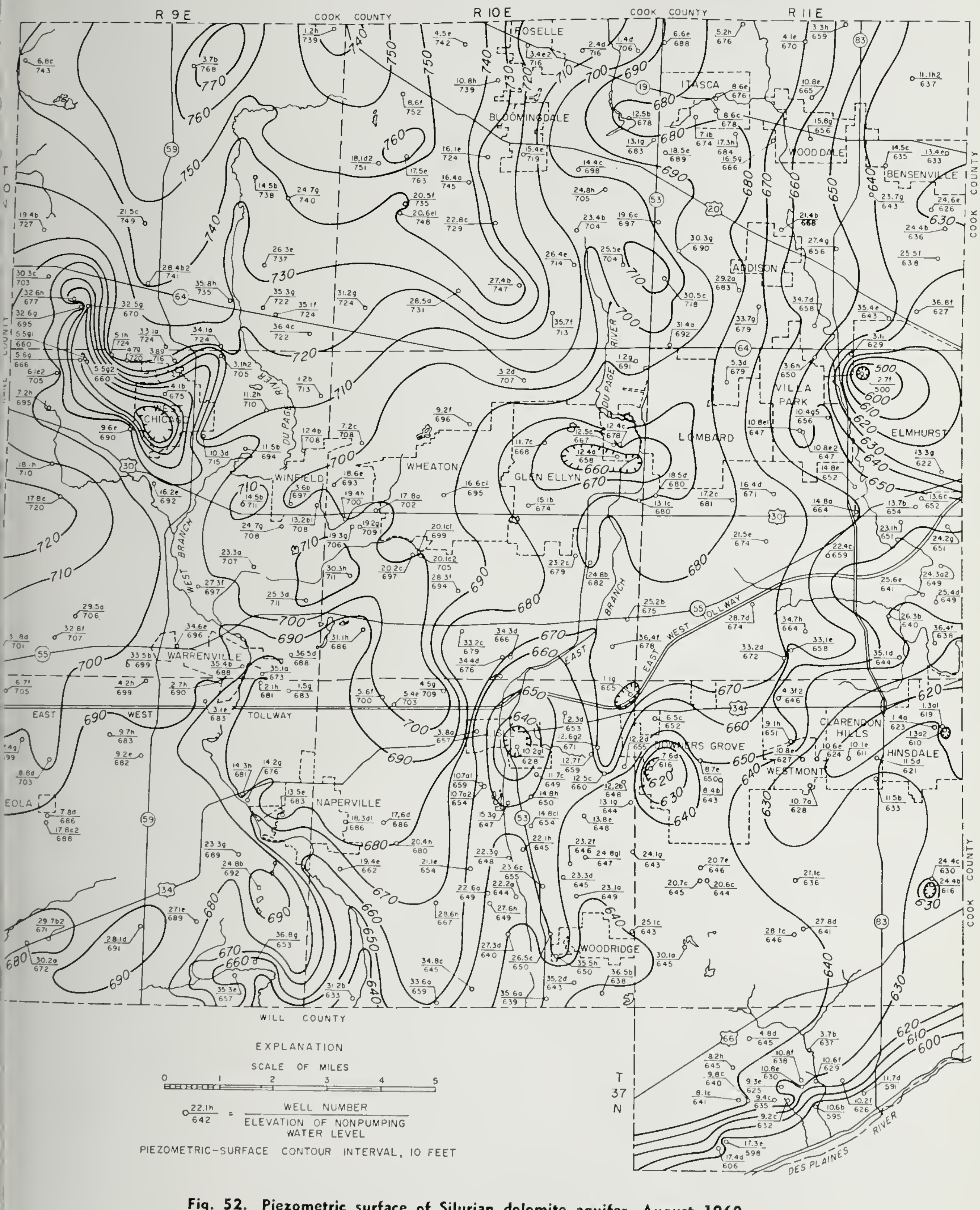


Fig. 52. Piezometric surface of Silurian dolomite aquifer, August 1960.

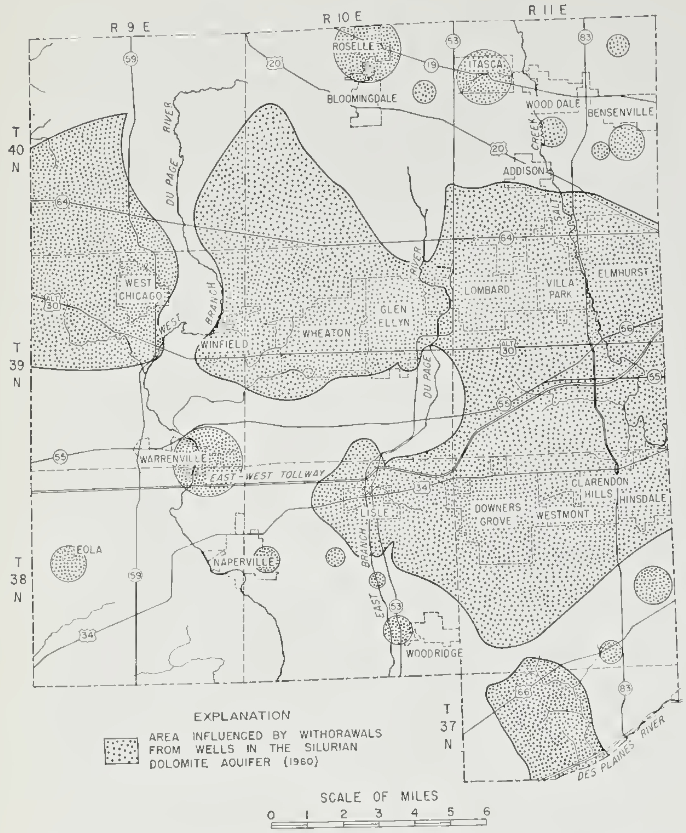


Fig. 53. Areas influenced by withdrawals from wells in the Silurian dolomite aquifer.

in 1960 was slow movement from all directions toward the deep cones of depression centered in the West Chicago, Lisle, Downers Grove-Westmont-Clarendon Hills-Hinsdale, and Wheaton-Glen Ellyn-Lombard areas, toward the East and West Branches of DuPage River, Salt Creek, and the Des Plaines River.

Water Levels

As illustrated by the hydrograph for well 39N11E-24.2g in figure 54, water levels in the Silurian dolomite aquifer generally recede in late spring, summer, and early fall when discharge by ground-water runoff streams and by pumping from wells is greater th recharge from precipitation. Water levels begin to cover in wells late in the fall, when pumping rates reduced and conditions are favorable for the infiltrat of rainfall, first to replenish the glacial drift and la to percolate to the Silurian dolomite aquifer. The r of water levels is especially pronounced in the spring months, when the ground-water reservoir recei most of its annual recharge. Maximum and minim annual water levels are recorded at different times the year depending primarily upon climatic and pun ing conditions.

According to the hydrographs in figure 55, wa levels in dolomite wells fairly remote from pumpi centers have a seasonal fluctuation ranging from 2 t feet and averaging 5 feet. The hydrographs of dolom wells in pumping centers shown in figures 56–59 in cate that in heavily pumped areas seasonal fluctuati may range from 3 to 15 feet in response to changes pumping rates. The location of observation wells shown in figure 60.

The first record of a water level in the Silurian dc mite aquifer is for a well at Lombard and was collec in 1907. Water-level data obtained mostly from St

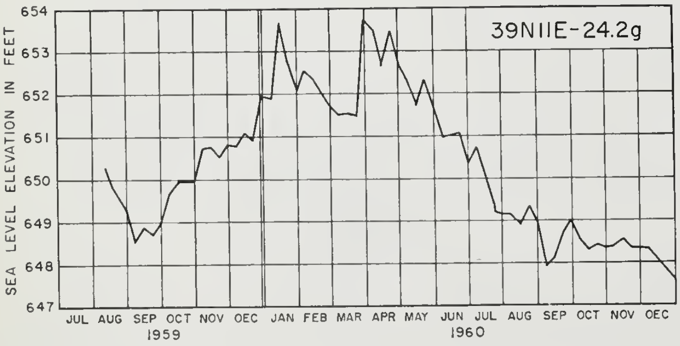


Fig. 54. Water levels in well 39N11E-24.2g, 1959-1960.

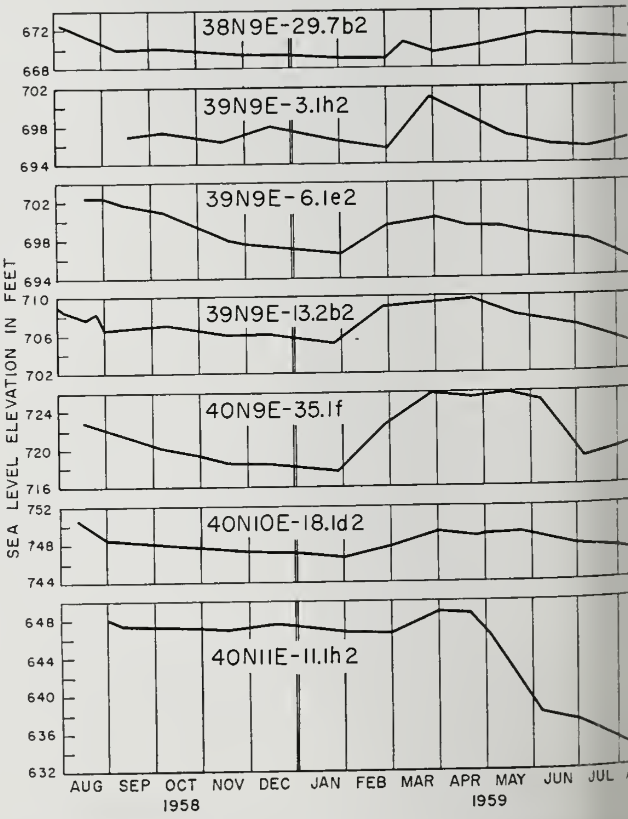
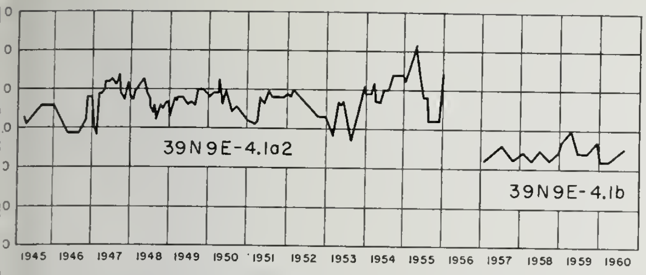
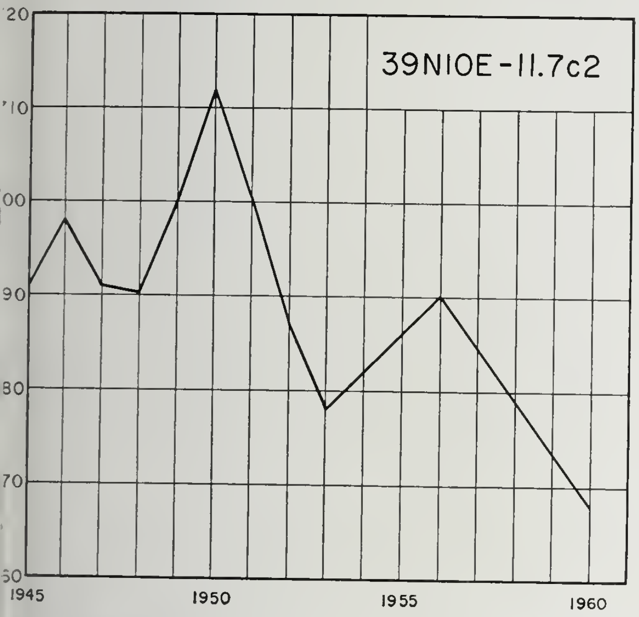


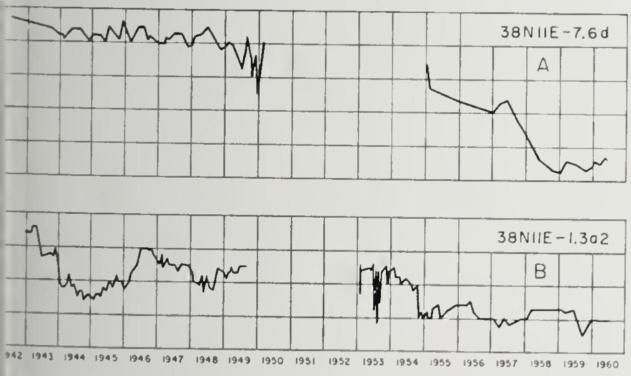
Fig. 55. Water levels in wells in the Silurian dolomite aqu 1958-1959.



. 56. Hydrographs of water levels in wells in the Silurian dolomite aquifer in the West Chicago area, 1945-1960.



57. Hydrograph of water levels in a well in the Silurian dolomite aquifer in the Wheaton-Glen Ellyn-Lombard pumping center, 1945-1960.



58. Hydrographs of water levels in wells in the Silurian dolomite aquifer in the Downers Grove area (A) and Hinsdale area (B), 1942-1960.

er Survey Bulletin 40 (1950) for the period 1907 ugh 1939 prior to heavy well development are sum- zed in table 10. A comparison of estimated early

Table 10. Water Levels in Wells in the Silurian Dolomite Aquifer for the Period 1907–1939 and for 1960

Location of well	Depth of well (*ft*)	Water level elevation (*ft*) early	Water level elevation (*ft*) 1960	Date of measurement of early water level	Water level decline (*ft*)
Roselle	182	733	716	1926	17
Itasca	184	684	676	1936	8
Villa Park	251	662	647	1925	15
Lombard	84	689	680	1907	9
Glen Ellyn	310	719	668	1916	51
Wheaton	175	717	695	1917	22
Winfield	200	714	697	1939	17
West Chicago	322	710	675	1915	35
Lisle	231	663	628	1926	35
Downers Grove	250	656	616	1928	40
Westmont	313	652	624	1926	28
Clarendon Hills	250	635	611	1932	24
Hinsdale	209	649	610	1924	39

water levels and the water levels measured in 1960 (table 10) indicates that the artesian pressure of the Silurian dolomite aquifer has lowered more than 10 feet in most of the pumping centers in response to heavy pumping. Water-level declines range from 8 feet at

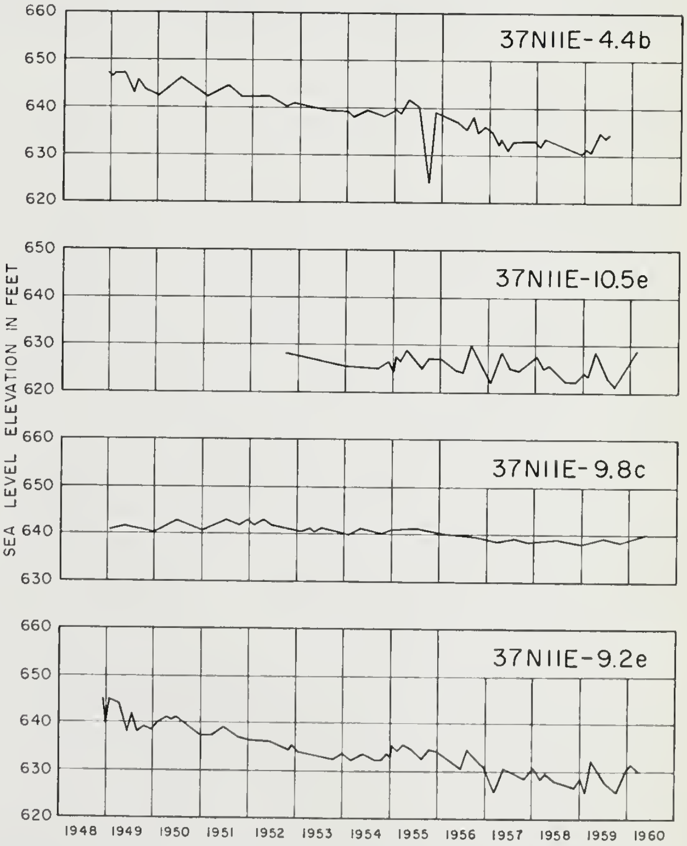


Fig. 59. Hydrographs of water levels in wells in the Silurian dolomite aquifer in the Argonne area, 1948-1960.

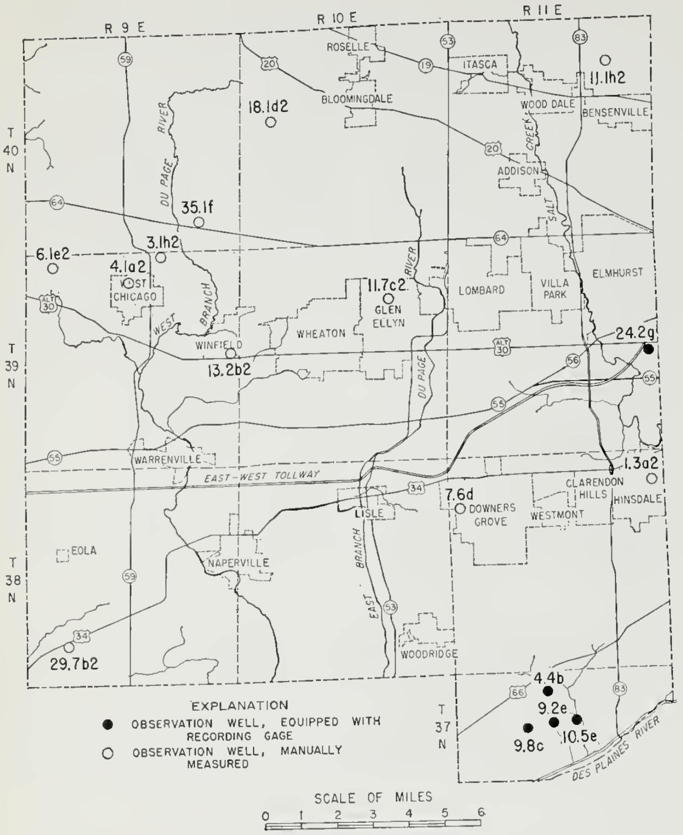


Fig. 60. Location of selected observation wells in the Silurian dolomite aquifer.

Itasca to 51 feet at Glen Ellyn and average about 26 feet.

Water levels in several dolomite wells have been measured periodically since 1942. Hydrographs for dolomite wells in the West Chicago, Glen Ellyn, Downers Grove, Hinsdale, and Argonne areas are given in figures 56–59. All the wells except those in the Argonne area are municipal wells and are near centers of heavy pumpage. The data in figure 59 were obtained by the U. S. Geological Survey during their study of ground-water conditions at the Argonne National Laboratory.

As the result of heavy pumping, the nonpumping water levels in dolomite wells declined from an elevation of 656 feet in 1942 to about 616 feet in 1960 at Downers Grove. The average rate of decline in this 18-year period was 2.2 feet per year and the total decline during the same period was 40 feet.

Water levels in dolomite wells at Hinsdale declined from an elevation of 635 feet in 1942 to about 610 feet in 1960. The total decline and average rate of decline in this 18-year period were 25 feet and 1.4 feet per year, respectively.

According to figure 56, water levels at West Chicago declined from an elevation of 685 feet in 1945 to about 675 feet in 1960. The average rate of decline in this
15-year period was about 0.7 foot per year and the to
decline was 10 feet.

The hydrograph of well 39N10E-11.7c2 in figure
shows that water levels in dolomite wells at Glen Ell
declined from an elevation of 691 feet in 1945 to 668 f
in 1960. The total decline and average rate of decl
during this 15-year period were 23 feet and 1.5 feet
year, respectively.

According to the hydrographs for wells 37N11E-4
and 37N11E-9.2e in figure 59, water levels at Argon
declined from an average elevation of 645 feet in 1
to 631 feet in 1960. The average rate of decline in t
11-year period was 1.3 feet per year and the total decl
was 14 feet.

RECHARGE

Recharge to the Silurian dolomite aquifer is deri
chiefly from vertical leakage through the glacial dr
The glacial drift is in turn recharged from precipi
tion. The rate of recharge to the Silurian dolom
aquifer can be estimated with a piezometric map a
past records of pumpage and water levels.

Areas of influence of production wells in area 1 (W
Chicago), area 2 (Wheaton-Glen Ellyn-Lombard), a
3 (Downers Grove-Westmont-Clarendon Hills-Hi

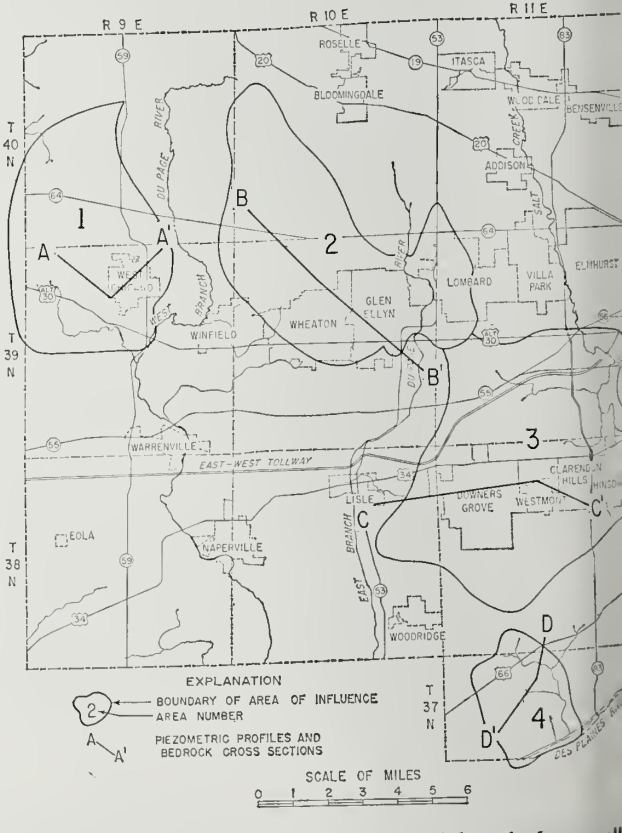


Fig. 61. Selected areas influenced by withdrawals from well the Silurian dolomite aquifer.

e), and area 4 (Argonne National Laboratory), as
wn in figure 61, were delineated with the piezometric
face map (fig. 52).

Comparisons of pumpage and water-level graphs for
areas of influence indicate that in general water-
el declines are directly proportional to pumping
es. The water levels in the dolomite vary greatly
m place to place within the areas and from time to
e mostly because of the shifting of pumpage from
l to well and variations in total well field pumpage;
vever, at no location is there any apparent continu-
decline that cannot be explained by pumpage
eases. Thus, within a relatively short time after
h increase in pumpage, recharge from vertical leakage
ough the glacial drift increased in proportion to
npage because vertical hydraulic gradients became
ater and areas of influence expanded. Therefore,
harge to the Silurian dolomite aquifer within any
ticular area of influence is equal to the total pump-
from dolomite wells in the area of influence.

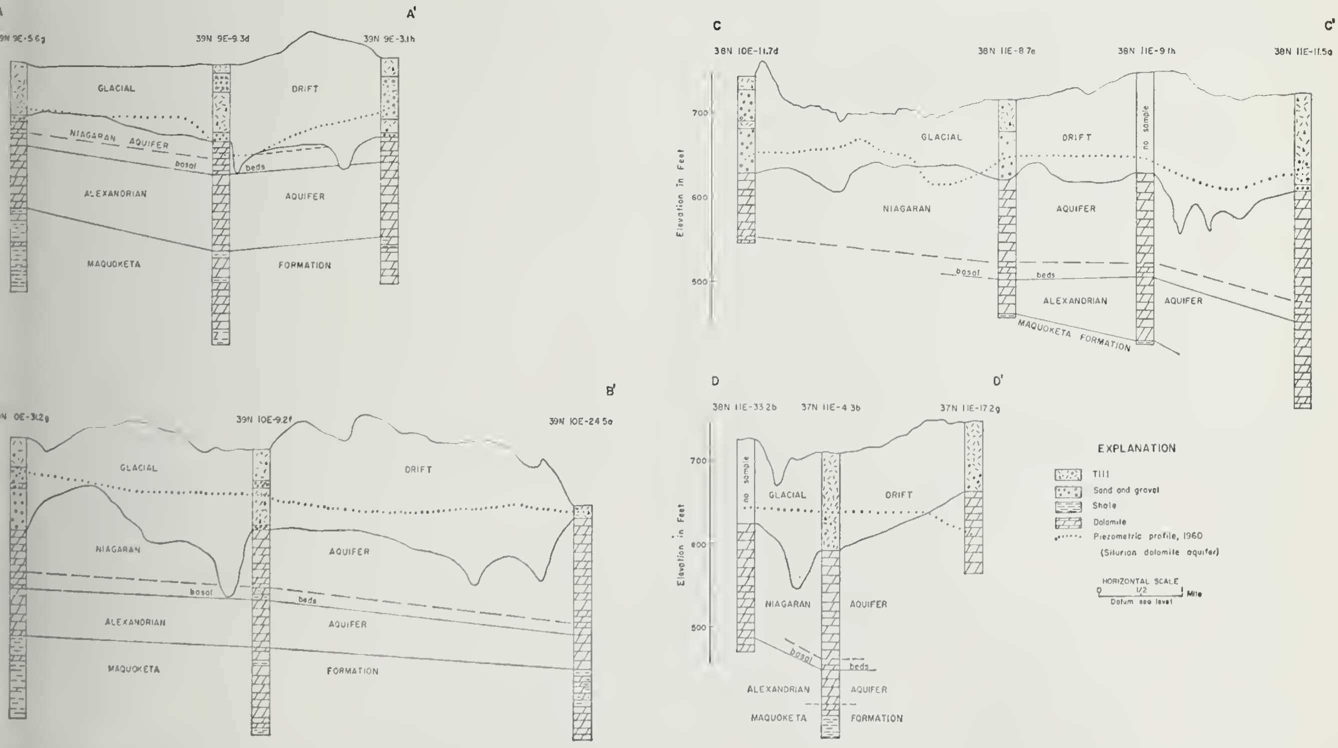
leasured areas of influence, pumpage data, and re-
rge rates computed as the quotient of pumpage and
are given in table 11. Recharge rates calculated
the areas of influence are approximately the same
the exception of area 1 where the recharge rate is
roximately one-half the rate computed for the other
e areas.

Table 11. Rates of Recharge to the Silurian Dolomite Aquifer

Area number	1960 pumpage (*mgd*)	Area (*sq mi*)	Recharge rate (*gpd/sq mi*)
1	1.8	28.0	64,000
2	4.5	32.5	138,000
3	6.3	46.2	136,000
4	1.2	7.6	158,000

Detailed investigations of the geohydrologic characteristics of the areas of influence were carried out to determine the cause of the lower recharge rate in area 1. Land surface topography within the areas of influence is, in general, quite similar. Studies of the character and distribution of the unconsolidated materials revealed no appreciable gross lithologic differences within the four areas of influence, and the glacial materials would not be expected to cause major differences in recharge to the Silurian dolomite aquifer.

The piezometric profiles of the Silurian dolomite aquifer in the cross sections of the areas of influence (fig. 62) show that the piezometric surface of the water in the aquifer is more than 50 feet below ground surface throughout most of the areas. Analysis of the piezometric surface of the Silurian dolomite aquifer and data on the position of the water table in the glacial drift show that average vertical hydraulic gradients do



62. Cross sections of the Silurian dolomite aquifer in the (A) West Chicago area, (B) Wheaton-Glen Ellyn-Lombard area, (C) Downers Grove-Hinsdale area, and (D) Argonne area.

not differ appreciably between the areas. The lower recharge rate in the West Chicago area cannot be explained on the basis of the presence of a smaller hydraulic gradient between the glacial drift and the Silurian dolomite aquifer in the West Chicago area.

The character of the upper part of the Silurian dolomite aquifer in the West Chicago area is considerably different than in the other three areas. As is shown by the map of the areal geology of the bedrock surface (fig. 7) and the cross sections of the areas of influence (fig. 62) much of the upper part of the Silurian dolomite aquifer in the West Chicago area is made up of the basal beds of the Niagaran Series. Most of the strata of the Niagaran Series above these beds have been removed by erosion in the West Chicago area but are present and are relatively thick in the other three areas. The basal beds of the Niagaran Series in the other three areas are encountered at considerable depths.

The dense, shaly dolomite and shale of the basal beds of the Niagaran Series may have restricted development of a weathered zone with solution-enlarged openings in the upper part of the dolomite and thereby restricted development of the permeability necessary for recharge to the underlying Alexandrian aquifer.

Other areas in DuPage County where recharge is probably low, or about the same as in the West Chicago area, are delineated by assuming that recharge to Silurian dolomite aquifer is limited east of the Niagar Alexandrian contact where rocks of the Niagaran aqui are less than 50 feet thick. In these areas, the sh basal beds of the Niagaran Series occur in the up part of the aquifer. The recharge rate is probably a low in areas where water is obtained from the Maquok Formation because permeable dolomite beds of formation are interbedded with and often overlain beds of shale and dolomitic shale with a very l permeability.

Areas where recharge is about the same as in areas 3, and 4 are delineated by assuming that recharge high west of the Niagaran-Alexandrian contact in rocks of the Alexandrian aquifer and east of Niagaran-Alexandrian contact where rocks of the agaran aquifer are more than 25 feet thick.

Estimated recharge rates for the Silurian dolom aquifer based upon these recharge rates, the geolo map of the bedrock surface (fig. 7), and the thickn of the Niagaran aquifer (fig. 19) are shown on the m in figure 63. It is probable that recharge to the Silur dolomite aquifer averages about 60,000 gpd/sq mi parts of the western one-third of the county and av ages about 140,000 gpd/sq mi in large areas of eastern two-thirds of the county.

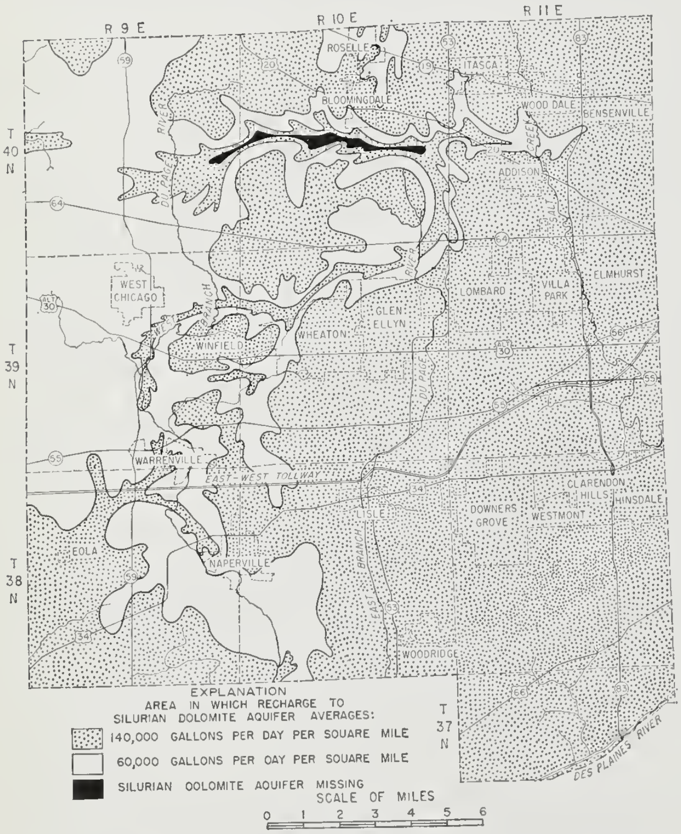
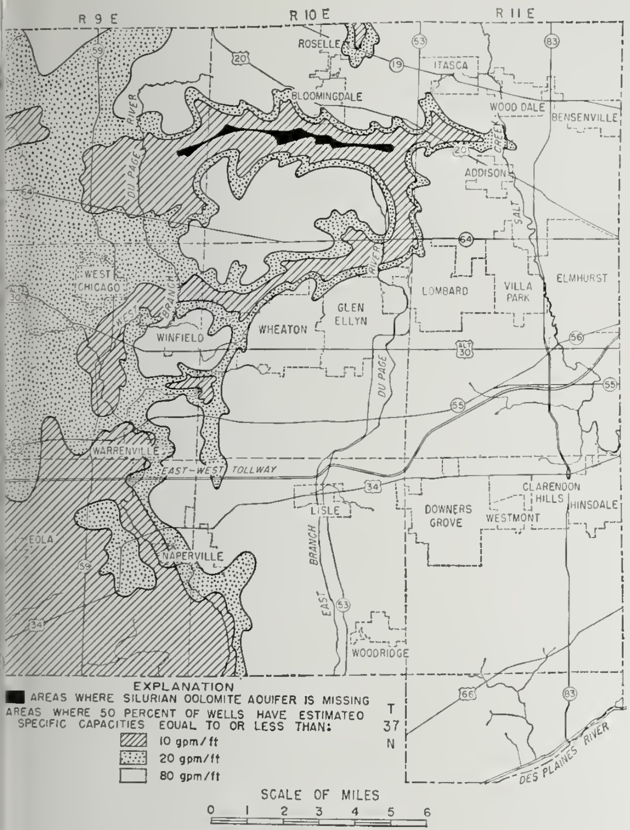


Fig. 63. Estimated recharge rates for the Silurian dolomite aquifer.

Probable Yields of Wells

Because the productivity of the Silurian dolom aquifer is inconsistent it is impossible to predict wit high degree of accuracy the yield of a well before dr ing at any location. Probable specific capacities of w in figure 64 were estimated as the product of the spec capacity per foot of penetration measured in 50 perc of the existing wells (fig. 51) and unit thicknesses (f 19–21). Specific capacities equal to or less than gpm/ft can be expected in large areas in the sou western and north-central parts of the county wh the Niagaran aquifer is thin or absent. Specific capa ties equal to or less than 20 gpm/ft can be expected areas in the western part of the county where the agaran aquifer is of moderate thickness and does exceed 50 feet in thickness. Specific capacities eq to or less than 80 gpm/ft can be expected in large ar in the eastern two-thirds of the county where the t thickness of the units of the Silurian dolomite aqui commonly exceeds 100 feet.

Probable specific capacities were in turn multipl by available drawdowns, based on water-level data figure 52 and thickness maps of the units, to estim the probable yields of wells which completely penetr the total thickness of the Silurian dolomite aqui Pumping levels were limited to depths below the of the Silurian dolomite aquifer equal to one-half



64. Estimated specific capacities of wells in the Silurian dolomite aquifer.

kness of the aquifer in areas where the Niagaran fer exceeds 25 feet in thickness, or one-quarter the kness of the aquifer where the Niagaran aquifer is ing or is less than 25 feet thick, or 100 feet which- was smaller in any particular case.

e probable range of yields of wells in the Silurian mite aquifer is shown in figure 65. It is possible rill what is essentially a dry hole at any location; ver, based on data for 50 percent of existing wells, hances of obtaining a well with a yield of 250 gpm ore are good in all areas except areas in the north- al part of the county where the Silurian dolomite fer is missing and the Maquoketa Formation im- ately underlies the glacial drift. The chances of ning a well with a yield of 500 gpm or more are in most areas in the eastern two-thirds of the ty. Thus, the yield of the Silurian dolomite aquifer obably high enough to support heavy industrial or cipal well development in all but a small part of ounty.

ntial Yield

cause the Silurian dolomite aquifer is thick, fairly y buried, and on a regional basis has high to rate permeabilities and great extent, areas of influence of production wells can extend for considerable distances and available water resources can be developed with a reasonably small number of wells and well fields. According to figure 53, there are large areas not influenced by present pumpage where heavy well development is possible, suggesting that the potential yield of the Silurian dolomite aquifer is much greater than present withdrawals. The potential yield is here defined as the maximum amount of ground water that can be developed from a reasonable number of wells and well fields without creating critical water levels or exceeding recharge.

Areas influenced by pumping include sites where the Silurian dolomite aquifer yields very little water to individual wells. In addition, the piezometric surface map in figure 52 is regular in appearance and could be favorably compared to piezometric surface maps for uniform sand and gravel or sandstone aquifers. These facts indicate that the inconsistency of the Silurian dolomite aquifer has little effect on the regional response of the aquifer to pumping and should not seriously deter the full development of available ground-water resources.

Well field specific capacity data (table 12) indicate that large quantities of water can be obtained from the

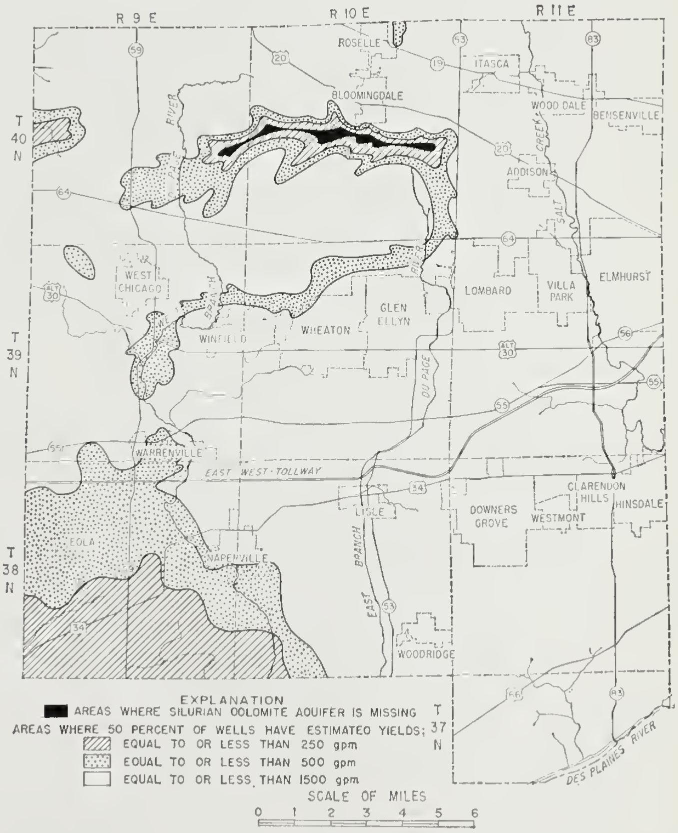


Fig. 65. Estimated yields of wells in the Silurian dolomite aquifer.

Table 12. Data on the Response of the Silurian Dolomite Aquifer to Heavy Pumping

Well number	Owner	Nonpumping water level elevation		Date of measurement		Decline in water level elevation (*ft*)	1960 pumping rate (*gpd*)	Specific capacity (*gpd/ft*)
		early	recent	early	recent			
DUP—								
37N11E-10.5f	Argonne National Lab.	648	612	1948	6/60	36	951,000	26,000
38N11E-7.6d	Village of Downers Grove	656	616	1928	7/60	40	1,901,000	48,000
39N9E-4.1a	City of West Chicago	710	675	1915	7/60	35	512,000	15,000
39N10E-11.7c	Village of Glen Ellyn	719	668	1916	6/60	51	1,268,000	25,000
39N10E-16.6cl	City of Wheaton	717	695	1917	6/60	22	2,000,000	91,000
39N11E-8.7h	Village of Lombard	689	680	1907	7/60	9	317,000	35,000
39N11E-10.8e2	Village of Villa Park	662	647	1925	7/60	15	265,000	18,000
40N11E-8.6e	Village of Itasca	684	676	1936	1960	8	189,000	24,000

Silurian dolomite aquifer. Specific capacities exceed 20,000 gpd/ft of drawdown in most places where data are available and the Silurian dolomite aquifer yields more than 40,000 gpd/ft in some heavily pumped areas.

Data on the response of the Silurian dolomite aquifer to heavy pumping and on yields of existing production wells indicate that the potential yield of the Silurian dolomite aquifer is limited by recharge. The potential yield of the Silurian dolomite aquifer in DuPage County is estimated to be about 38 mgd based on the recharge rates in figure 63. Artificial recharge was not considered in the computation of potential yield.

PRACTICAL SUSTAINED YIELD OF EXISTING PUMPING CENTERS

In 1960 large parts of DuPage County were influenced by pumping from the Silurian dolomite aquifer. Many pumping centers are so closely spaced that individual cones of depression overlap and there is competition between pumping centers for areas unaffected by pumping. Interference between pumping centers affects values of discharge and drawdown in individual wells. This situation is particularly apparent in parts of the county from Lisle east through Hinsdale and from Winfield east through Elmhurst. Room for future expansion of areas of influence is limited.

The nonpumping water levels in wells in parts of the West Chicago, Glen Ellyn, Downers Grove, Clarendon Hills, Hinsdale, and Argonne areas were below the top of the Silurian dolomite aquifer in 1960. The yields of production wells will continually decrease as more of the aquifer is dewatered. Declines in yield will probably become critical after one-half of the Niagaran aquifer is dewatered at places where the thickness of these rocks exceeds 25 feet and after one-quarter of the Alexandrian aquifer is dewatered at place where the Niagaran aquifer is missing or is less than 25 feet thick. Therefore, available drawdown in pumping centers is limited.

In 1960 nonpumping water levels were not critical in any pumping center and there were areas unaffected by pumping. Thus, the practical sustained yield of exi
ing pumping centers exceeds total withdrawals in 19
The practical sustained yield is here defined as the ra
at which ground water can be continuously withdra
from wells in existing pumping centers without loweri
water levels to critical stages and without exceedi
recharge.

Drawdowns available for future increases in pumpa
were estimated for pumping centers from the unit thic
nesses and the piezometric surface map of the Siluri
dolomite aquifer (figs. 19, 21, and 52). It was assum
that critical water levels will result if more than o
half of the Niagaran aquifer is dewatered at plac
where the thickness of these rocks exceeds 25 feet a
after one-quarter of the Alexandrian aquifer is
watered at places where the Niagaran aquifer is missi
or is less than 25 feet thick. The amounts of water t
can be withdrawn from pumping centers in addition
withdrawals in 1960 without creating critical wat
level conditions were estimated as the products of ava
able drawdowns and the well field specific capacit
given in table 12. Estimated additional withdraw
were added to pumping rates in 1960 to obtain to
allowable withdrawals.

The areas of influence necessary for a balance betwe
total allowable withdrawals and recharge were estimat
with the recharge rates in figure 63 and were sketch
on a map of DuPage County using the areas influenc
by withdrawals in the Silurian dolomite aquifer (f
53) as a guide. In some cases it was found that are
of influence needed for balance were unreasonably lar
and needs were greater than that available from
areas unaffected by pumping in 1960, indicating t
the practical sustained yield is limited not by criti
water levels but by recharge. In these cases the practi
sustained yields were estimated as the products of ava
able areas unaffected by pumping within the county
1960 and recharge rates in figure 63. In the other ca
the sum of the estimated additional withdrawals ba
on critical water levels and total withdrawals in 1
are the practical sustained yields. Estimated practi

ained yields of pumping centers are given in table
Artificial recharge was not considered in the compu-
on of practical sustained yield.

Table 13. Estimated Practical Sustained Yields of Pumping Centers

Pumping center	1960 pumping rate (*mgd*)	Additional possible withdrawal (*mgd*)	Practical sustained yield (*mgd*)	Year after which practical sustained yield may be exceeded
ners Grove-Clarendon lls-Hinsdale area	6.3	1.5	7.8	1964
nne area	1.2	1.0	2.2	1967
urst-Villa Park area	2.0	0.5	2.5	1971
son area	1.0	1.5	2.5	1970
a area	0.4	1.6	2.0	1985
le area	0.6	0.5	1.1	1966
ton-Glen Ellyn- mbard area	4.8	1.9	6.7	1970
area	0.8	1.8	2.6	1975
Chicago area	1.9	0.8	2.7	1971
enville area	0.4	1.6	2.0	1979
rville-Eola area	0.6	2.0	2.6	1985
otal	20.0	14.7	34.7	

ie total practical sustained yield (about 35 mgd) is
t 92 percent of the potential yield (38 mgd) of the
rian dolomite aquifer. Thus, nearly all of the poten-
ield of Silurian dolomite aquifer can be developed
scattered production wells in existing pumping
rs. About 3 mgd is beyond the reach of existing
ping centers mostly in areas in the northwestern
southwestern parts of the county.

tes after which withdrawals in existing pumping
rs are likely to exceed the practical sustained yields
estimated by extrapolating pumpage graphs in
s 30–33. No great accuracy is inferred for the
ated dates in table 13; they are given only to aid
e water planning. If pumpage continues to grow
e future as it has in the past 10 years, the practical
ined yields of several pumping centers will proba-
e exceeded within 2 to 5 years and the practical
ined yields of all pumping centers will be exceeded
985. A reasonable extrapolation of the pumpage
h curve in figure 28 suggests that total ground-
withdrawals from wells in the Silurian dolomite
er in DuPage County will exceed the potential
of the Silurian dolomite aquifer by about 1977.

GLACIAL DRIFT AQUIFERS

cial drift aquifers in large areas of the county are
ydraulic connection with the Silurian dolomite
er. Pumping from basal sand and gravel aquifers
as where recharge to the Silurian dolomite aquifer is not retarded by the shaly basal beds of the Niagaran Series will reduce recharge to, and therefore the potential yield of, the Silurian dolomite aquifer. In these areas most of the sand and gravel aquifers complement the Silurian dolomite aquifer, thus mutually supplying each other's lack. The total potential yield of these aquifers is equal to the potential yield of the Silurian dolomite aquifer and the presence of the glacial drift aquifers only serves to make development of available ground water resources less difficult.

In areas where recharge to the Silurian dolomite aquifer is retarded, the basal and interbedded sand and gravel deposits supplement the Silurian dolomite aquifer. The potential yield of the glacial drift aquifers is in addition to the potential yield of the Silurian dolomite aquifer and is limited to the difference between the recharge rates of the Silurian dolomite and glacial drift aquifers.

In areas where fairly extensive sand and gravel deposits occur at shallow depths these deposits also supplement the Silurian dolomite aquifer.

The map in figure 66 was prepared by assuming that the glacial drift aquifers supplement the Silurian dolomite aquifer in areas where basal sand and gravel deposits exceed 20 feet in thickness and the shaly dolo-

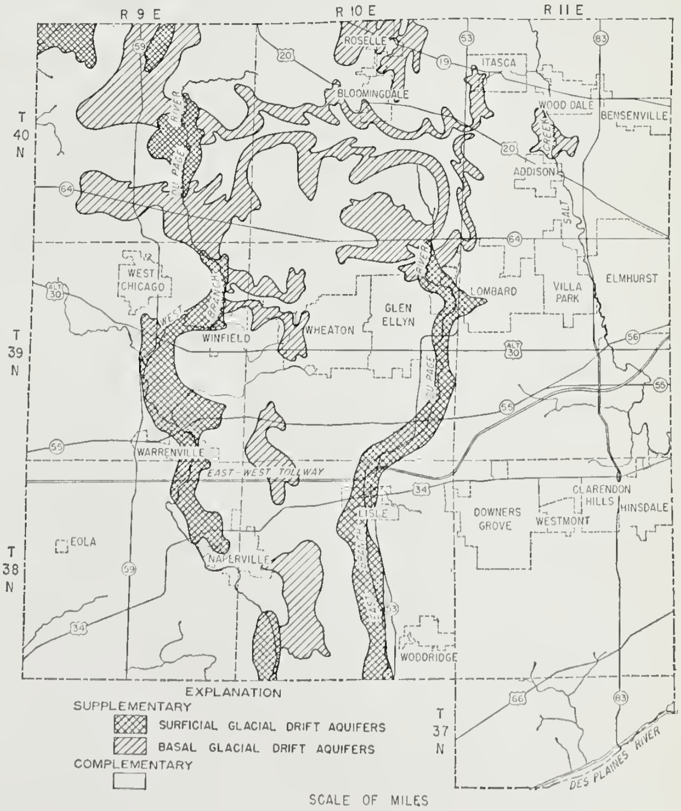


Fig. 66. Relationship of glacial drift aquifers to dolomite aquifers.

mite beds retard recharge and where surficial glacial drift aquifers occur. Throughout the rest of the county, the glacial drift aquifers complement the Silurian dolomite aquifer. The potential yield of the glacial drift aquifers supplements the potential yield of the Silurian dolomite aquifer in large areas in the western one-third of the county.

Specific Capacity Data

Available specific capacity data for wells in the glacial drift aquifers are summarized in table 14. Specific capacities range from 1.0 to 40.7 gpm/ft. Data in table 14 and in Cooperative Report 1 suggest that the yield of sand and gravel aquifers is probably high enough to support heavy industrial or municipal well development in many areas in the county.

Table 14. Specific Capacity Data for Wells in the Glacial Drift Aquifers

Location and owner	Depth of well (ft)	Diam. of casing (in)	Screen length (ft)	Screen diam. (in)	Date of test	Non-pumping level (ft)	Pumping rate (gpm)	Draw-down (ft)	Specific capacity (gpm/ft)
Bloomingdale, Medinah Country Club	68	8	15	16	1956	14	1100	27	40.7
Elmhurst, Standard Oil Company	218	8			1958	25	60	62	1.0
Lemont, State Geological Survey	75	10	14	7	1943	19.5	273	24.8	11.0
Lombard, York Center Community Co-op	81	6	10	6	1960	37	150	5.5	2.7

Water Levels

Relatively few wells completed in the glacial drift aquifers were available for water-level measurements. Monthly measurements (fig. 67) were taken over a period of one year in several wells scattered throughout the county. The water levels in a shallow dug well west of Naperville were continuously measured with a recorder during 1959 and 1960. A hydrograph for the well is shown in figure 68.

Hydrographs of the water levels in the glacial drift wells show a pattern of seasonal fluctuation similar to the hydrographs of water levels of wells completed in the Silurian dolomite aquifer. Most of the water levels in glacial drift wells are affected to a greater degree by precipitation than are water levels in Silurian dolomite wells. Year end water levels vary from year to year chiefly because of climatic conditions. The water level is well 38N9E-22.3f was about 4 feet lower in December 1960 than it was in December 1959 largely because precipitation during the late fall months of 1960 was below normal and precipitation during the late fall months of 1959 was near normal. The hydrographs indicate no general or permanent decline in water levels.

Recharge

Recharge to basal sand and gravel deposits is assum to be approximately equal to the rate of recharg (140,000 gpd/sq mi) to the underlying Silurian dol mite aquifer in areas where shaly dolomite beds do n retard the vertical movement of water. The rate recharge to the fairly extensive surficial sand and grav aquifers was estimated on the basis of stream flo studies in DuPage County and sand and gravel aquif studies in other parts of Illinois.

Stream Flow Analysis

Ground-water runoff to streams in the two drainag basins shown in figure 69 was estimated with strea flow hydrograph separation methods outlined b Linsley, Kohler, and Paulhus (1958). Daily mea stream flow data published by the U. S. Geological Su

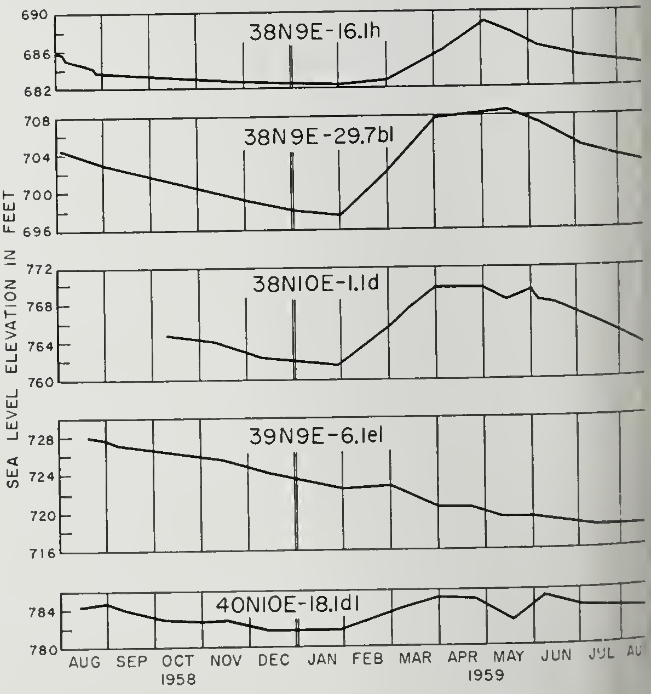
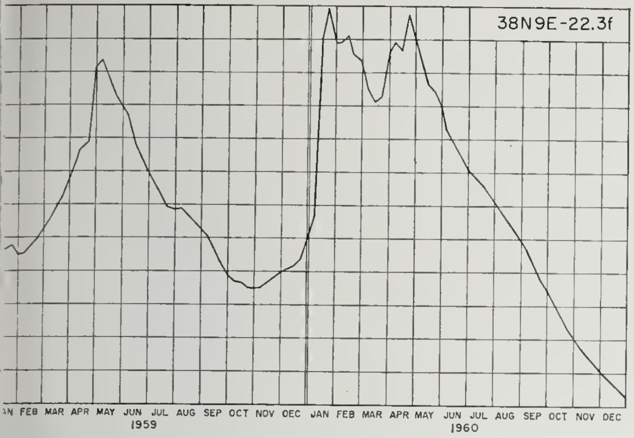


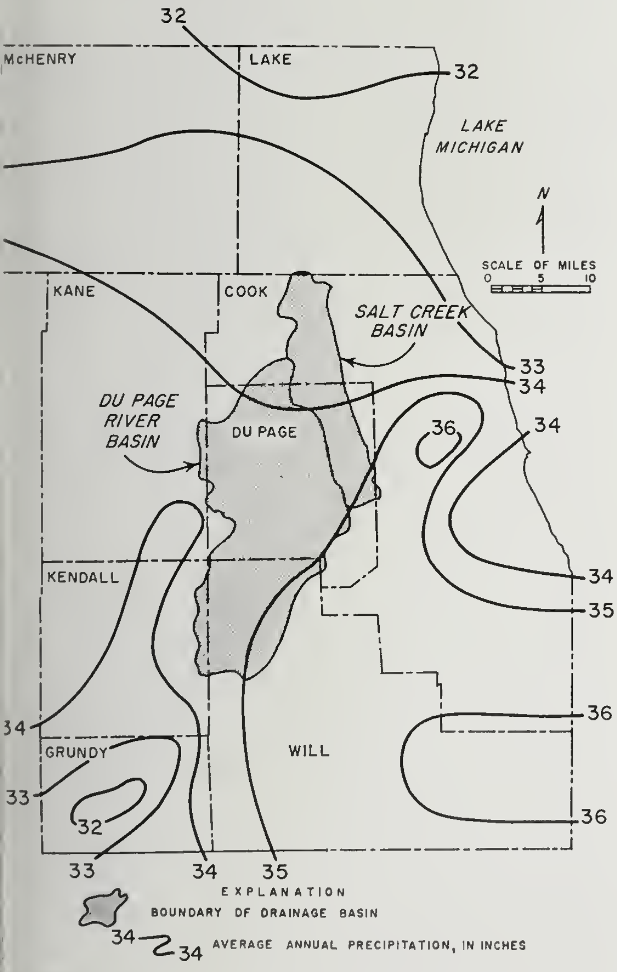
Fig. 67. Water levels in wells in the glacial drift aquife 1958-1959.



ig. 68. Water levels in well 38N9E-22.3f, 1959-1960.

for two stream gaging stations, Salt Creek at tern Springs and DuPage River at Troy, were stigated.

ecords for the 10-year period 1948 through 1957 for two gaging stations were analyzed to determine how nd-water runoff varies from year to year with climatic conditions. Daily ground-water runoff was plotted beneath stream flow hydrographs and lines were drawn connecting points to describe ground-water hydrographs as illustrated in figure 70. The shaded areas between stream flow and ground-water runoff hydrographs represent surface runoff. Annual ground-water and surface runoff for the period 1948 to 1957, expressed in inches of water over the DuPage River and Salt Creek basin, are given in table 15.



9. Special study drainage basins in the Chicago region.

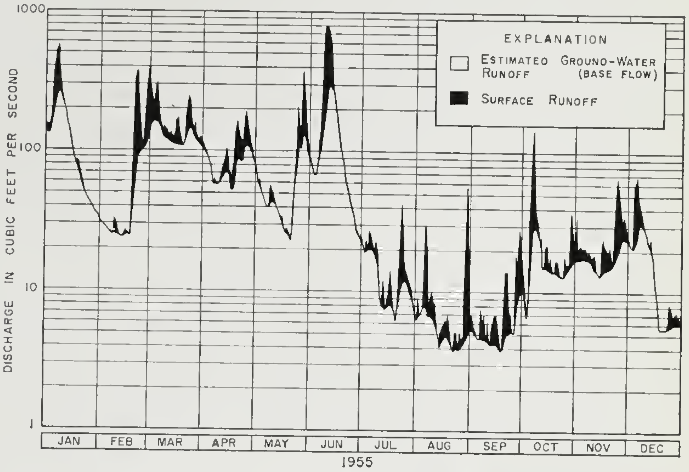


Fig. 70. Stream flow at Western Springs gaging station, Salt Creek drainage basin, 1955.

Ground-water runoff ranged from 9.45 to 2.90 inches

Table 15. Estimated Annual Ground-Water and Surface Runoff from DuPage River and Salt Creek Drainage Basins

Calendar year	Ground-water runoff (*in*)	Surface runoff (*in*)	Total stream flow (*in*)
	DuPage River basin		
1948	5.46	4.07	9.53
1949	4.31	2.79	7.10
1950	8.34	4.28	12.62
1951	9.45	4.05	13.50
1952	6.72	2.94	9.66
1953	3.90	1.71	5.61
1954	7.64	5.99	13.63
1955	7.71	2.85	10.56
1956	2.90	1.23	4.13
1957	5.42	2.54	7.96
	Salt Creek basin		
1948	4.97	5.01	9.98
1949	3.20	3.81	7.01
1950	7.94	4.37	12.31
1951	8.96	5.19	14.15
1952	7.89	3.52	11.41
1953	2.75	1.21	3.96
1954	6.90	4.84	11.74
1955	5.81	3.14	8.95
1956	2.95	1.78	4.73
1957	7.30	4.07	11.37

in the DuPage River basin and from 8.96 to 2.75 inches in the Salt Creek basin. Differences in maximum and minimum annual ground-water runoff from the two basins are small. Ground-water runoff during the period 1948 to 1957 averaged about 66 percent of stream flow from the Salt Creek basin. Maximum, minimum, and near average ground-water runoff occurred during the years 1951, 1956, and 1948 respectively. Precipitation was 5.15 inches above normal in 1951, 12.04 inches below normal in 1956, and near normal in 1948.

Data in table 15 indicate that the years 1951, 1956, and 1948 are best for studies to determine how geohydrologic and climatic conditions affect ground-water runoff and, therefore, ground-water recharge.

Some of the discharge from the basins heretofore labeled ground-water runoff is sewage. Sewage is water from shallow aquifers, the Cambrian-Ordovician and Mt. Simon aquifers, and surface sources. Water pumped from shallow aquifers was diverted from stream flow and under natural conditions would have reached the streams as ground-water runoff. Thus, water pumped from shallow aquifers within a drainage basin and discharged as sewage within the same drainage basin may be considered ground-water runoff. However, water obtained from the Cambrian-Ordovician and Mt. Simon aquifers would not under natural conditions reach streams because these aquifers are not in hydraulic connection with the surface streams. It is necessary to subtract sewage derived from the Cambrian-Ordovician and Mt. Simon aquifers and surface sources from observed ground-water runoff to determine actual ground-water runoff from shallow aquifers. Annual ground-water runoff from the two basins adjusted for sewage is given in table 16.

Table 16. Annual Ground-Water Runoff Adjusted for Sewage from DuPage River and Salt Creek Drainage Basins

Drainage basin	Calendar year	Ground-water runoff (*in*)	Deep aquifer and surface source sewage (*in*)	Ground-water runoff adjusted for sewage (*in*)
Salt Creek	1948	4.97	0.25	4.72
Salt Creek	1951	8.96	0.36	8.60
Salt Creek	1956	2.95	0.69	2.26
DuPage River	1948	5.46	0.02	5.44
DuPage River	1951	9.45	0.02	9.43
DuPage River	1956	2.90	0.04	2.86

Many factors influence ground-water runoff. The characteristics of soils, land use, position of the water table, and amount and distribution of precipitation are but a few of the more important factors. Taking into consideration that stream flow measurements are accurate within 5 to 10 percent, and estimates of ground-water runoff are probably accurate within 10 perce the apparent differences in ground-water runoff fr basin to basin less than 15 percent of average grou- water runoff may not be real.

Not all ground-water runoff can be diverted i cones of influence because even under heavy pumpi conditions there is lateral as well as vertical movem of ground water in the glacial deposits and recharge the water table is unevenly distributed throughout year. Studies of the character of the unconsolida material shows that the gross lithologic character of materials in the DuPage River and Salt Creek bas are similar. It is probable that the average grou- water runoff from areas 2, 3, and 4 under natural con- tions was about the same as from Salt Creek basin a was about 5.19 inches. The average rate of recharge the Silurian dolomite aquifer and therefore to sand a gravel deposits near the base of the glacial drift in ar 2, 3, and 4 was computed to be 140,000 gpd/sq mi about 3.0 inches. Based on the quotient of rate of charge and ground-water runoff, it is estimated t about 58 percent of ground-water runoff can be diver into cones of influence to recharge production wells deeply buried glacial drift aquifers.

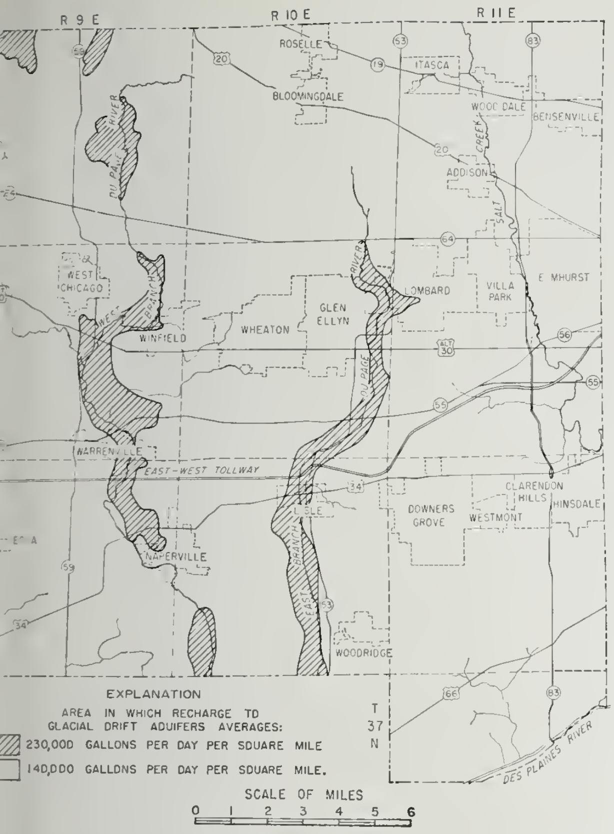
Surficial sand and gravel deposits occur within e of the two basins and locally increase ground-wa runoff; however, on a regional basis, these deposits h very little influence on average ground-water run because less permeable deposits predominate. Ba upon recent studies at Taylorville (Walker and Walt 1961), stream flow studies in central Illinois (Schi and Walton, 1961) and in northeastern Illinois, and above 58 percent factor, the average rate of recharge the surficial sand and gravel aquifers was estimated be about 4.7 inches or 230,000 gpd/sq mi.

Figure 71 is a map showing estimated recharge ra for the glacial drift aquifers. Except in small ar where surficial sand and gravel deposits occur it probable that recharge to the glacial drift aquif averages about 140,000 gpd/sq mi.

POTENTIAL YIELD

The potential yield of the glacial drift aquifers estimated (from figs. 66 and 71) to be about 3 mgd. assumption was made that conditions are favorable development of well fields and available ground-wa resources in about 50 percent of areas where gla drift aquifers supplement the Silurian dolomite aqui

The potential yield of the glacial drift aquifers estimated by assuming full development of the Silur dolomite aquifer and supplemental development glacial drift aquifers. In many areas full developm of glacial drift aquifers and supplemental developm of the Silurian dolomite aquifer may be advantage



71. **Estimated recharge rates for the glacial drift aquifers.**

, it is possible to obtain more water from the glacial
aquifers than computed and correspondingly less
r from the Silurian dolomite aquifer. The potential
of the glacial drift aquifer (3 mgd) greatly ex-
withdrawals from drift wells (0.52 mgd) in 1960.

Ambrian-Ordovician and Mt. Simon Aquifers

ailable data indicate that on a regional basis the
sequence of strata, from the top of the Galena-
eville Dolomite to the top of the shale beds of the
Claire Formation, behaves hydraulically as one
er (Cambrian-Ordovician aquifer) in northeastern
is. Shale beds of the Maquoketa Formation above
alena-Platteville Dolomite greatly retard the verti-
ovement of ground water and confine the water in
ambrian-Ordovician aquifer under leaky artesian
tions. The Cambrian-Ordovician aquifer receives
from overlying glacial deposits mostly in areas of
McHenry, Kendall, Boone, and DeKalb Counties
the Galena-Platteville Dolomite is the uppermost
ck formation below the glacial deposits. This is
of the border of the Maquoketa Formation in areas
ging about 15 miles west of DuPage County. Re-
of the glacial deposits occurs from precipitation
alls locally.

The Mt. Simon Sandstone and lower sandstones of the Eau Claire Formation are hydrologically interconnected. Shale of the middle and upper beds of the Eau Claire Formation greatly retards the vertical movement of water and confines the water in the Mt. Simon aquifer under leaky artesian conditions. There are significant differences in hydrostatic head between the Mt. Simon and Cambrian-Ordovician aquifers. Based on drillers' reports, the hydrostatic head in the Mt. Simon aquifer was about 50 feet higher than the hydrostatic head in the Cambrian-Ordovician aquifer in 1960 in many parts of the county.

Hydraulic Properties

During the period 1943 to 1954, seven pumping tests were made in DuPage County to determine the hydraulic properties of the Cambrian-Ordovician aquifer. A summary of the coefficients of transmissibility obtained from the various pumping tests is given in table 17. Coefficients of transmissibility range from 14,700 to 22,000 gpd/ft and average 18,000 gpd/ft. The average coefficient of storage is estimated to be about 0.00035 based on data in Cooperative Report 1.

Table 17. Coefficients of Transmissibility of the Cambrian-Ordovician Aquifer

Well owner	Depth of well *(ft)*	Date of test	Pumping rate *(gpm)*	Coefficient of transmissibility *(gpd/ft)*
Village of Bensenville	1445	1954	230	17,800
City of Elmhurst	1480	1944	625	18,000
City of Elmhurst	1480	1944	920	14,700
City of Elmhurst	1502	1943	950	18,300
City of Elmhurst	1400	1948	620	18,200
Village of Lombard	2062	1954	1200	22,000
Wander Company	1987	1954	2390	17,600

The coefficient of transmissibility is fairly uniform throughout large areas in the county and decreases to the southeast.

Specific Capacity Data

During the period 1927 to 1960, well-production tests were made by the State Water Survey on 34 deep sandstone wells in the county. The results of the tests are summarized in table 18. The lengths of tests range from 1 hour to 24 hours and average about 9 hours. Pumping rates range from 70 to 2310 gpm and average about 910 gpm. Diameters of inner casings range from 6 to 20 inches and the average diameter of inner casings is about 12 inches.

Specific capacities exceeding 10 gpm/ft are mostly for wells penetrating both the Cambrian-Ordovician and Mt. Simon aquifers or for wells which were shot prior to the well-production test. The average specific capacity

Table 18. Specific Capacity Data for Wells in the Cambrian-Ordovician and Mt. Simon Aquifers

Well number	Owner	Units or aquifers contributing to yield of well	Diam. of inner casing (in)	Date of test	Length of test (hr)	Pumping rate (gpm)	Observed specific capacity (gpm/ft)	Remarks
DUP—								
40N11E-35.5e	City of Elmhurst	C-O*	20	1953	8	570	21.9	City Well No. 6, shot
40N11E-35.5e	City of Elmhurst	C-O	20	1953	8	1270	15.3	City Well No. 6, shot
40N11E-31.7a	Village of Lombard	C-O	20	1956	24	1025	9.8	Village Well No. 5
40N11E-14.1d	Village of Bensenville	C-O	16	1954	24	1050	14.0	Village Well No. 3, sh
40N11E-13.8el	Village of Bensenville	C-O	6	1934	8	147	6.1	Village Well No. 1
40N11E-13.8el	Village of Bensenville	C-O	6	1947	2	225	2.7	Village Well No. 1
40N11E-13.8e2	Village of Bensenville	C-O	10	1934	10	400	11.7	Village Well No. 2
40N11E-13.8e2	Village of Bensenville	C-O	10	1950	1	630	9.3	
40N11E-13.5b	C.M.St.P.&P.R.R.	C-O	16	1950	1	400	14.3	Well No. 6
40N11E-13.5b	C.M.St.P.&P.R.R.	C-O	16	1950	1	600	12.5	Well No. 6
40N11E-13.5b	C.M.St.P.&P.R.R.	C-O	16	1950	1	725	10.4	Well No. 6
39N11E-12.8c	City of Elmhurst	C-O	12	1941	....	990	9.7	City Well No. 5
39N11E-12.8d	City of Elmhurst	C-O	12	1956	....	1000	7.0	City Well No. 5
39N11E-10.4g	Wander Company	C-O,MS	12	1945	8	1100	13.3	Well No. 7
39N11E-10.3gl	Wander Company	C-O,MS	12	1933	1	1513	11.6	Well No. 9
39N11E-10.3gl	Wander Company	C-O,MS	12	1933	1	2310	10.8	Well No. 9
39N11E-10.3gl	Wander Company	C-O,MS	12	1944	....	1900	9.7	Well No. 9
39N11E-10.3g2	Wander Company	C-O,MS	16	1946	24	1160	8.7	Well No. 11
39N11E-10.1h	City of Elmhurst	C-O,MS	14	1953	....	1000	12.8	City Well No. 4
39N11E-10.1h	City of Elmhurst	C-O,MS	14	1956	....	700	10.9	City Well No. 4
39N11E-9.1h	Village of Villa Park	C-O,MS	....	1947	3	625	8.1	Village Well No. 2
39N11E-8.7h	Village of Lombard	C-O,MS	10	1948	1	102	7.9	Village Well No. 2
39N11E-8.7h	Village of Lombard	C-O,MS	10	1948	1	198	6.8	Village Well No. 2
39N11E-8.7h	Village of Lombard	C-O,MS	10	1948	1	337	5.7	Village Well No. 2
39N11E-6.7a	Village of Lombard	C-O,MS	20	1954	22	1000	13.2	Village Well No. 6
39N11E-6.5a	Village of Lombard	C-O,MS	20	1954	10	1005	14.7	Village Well No. 4, sh
39N11E-4.1a	Village of Villa Park	C-O	16	1956	24	842	7.5	Village Well No. 7
39N11E-1.8gl	City of Elmhurst	C-O	10	1944	2	625	11.2	City Well No. 1
39N11E-1.8gl	City of Elmhurst	C-O	10	1956	....	700	4.4	City Well No. 1
39N11E-1.8g2	City of Elmhurst	C-O,MS	8	1956	....	1100	11.0	City Well No. 2
39N9E-15.7h	City of West Chicago	C-O	....	1960	1	950	7.6	Well No. 4
39N9E-15.7h	City of West Chicago	C-O	....	1960	3	530	13.9	Well No. 4, shot
38N11E-10.2f	Village of Clarendon Hills	G-P,G-SP	6	1927	24	70	0.8	
38N9E-13.2b3	City of Naperville	C-O	20	1958	24	1070	7.1	City Well No. 7

* See Appendix A for abbreviations.

of wells penetrating the Cambrian-Ordovician aquifer and not shot is about 9.7 gpm/ft. The average specific capacity of wells penetrating both the Cambrian-Ordovician and Mt. Simon aquifers is about 11.4 gpm/ft.

Step-drawdown tests were made on three deep sandstone wells in the county. Computed values of well-loss constants are given below:

Well number	Average C (sec^2/ft^5)
DUP 40N11E-13.5b	10
DUP 40N11E-35.5e	6
DUP 39N11E-10.3g	1

Yields of Individual Bedrock Units

Most deep sandstone wells tap several bedrock units and are multiunit wells. The specific capacity of a multiunit well is the numerical sum of the specific capacities of the individual units. The yields of individual units were evaluated by Walton and Csall (1962).

In DuPage County, the Galena-Platteville Dolo generally yields very little or no water to wells. average specific capacity of a well penetrating Galena-Platteville Dolomite and 200 feet of the G wood-St. Peter Sandstone is about 1.0 gpm/ft f pumping period of 8 hours. The specific capacity creases with thickness of the Glenwood-St.Peter S stone but is not directly proportional to thickness. specific capacity for a thickness of 300 feet is a 1.6 gpm/ft.

The combined yield of the Prairie du Chien Se Trempealeau Dolomite, and Franconia Formation well averages about 2.9 gpm/ft.

The average specific capacity of wells in the Iro Galesville Sandstone, 3.2 gpm/ft, is about three t average specific capacity of wells in the Glenwood-Peter Sandstone. The Ironton-Galesville Sandstone onsidered the best bedrock aquifer in Illinois because its consistently high yield. From data given by Wal- and Csallany (1962), the average permeability of Ironton-Galesville Sandstone is twice that of the Simon aquifer.

he average specific capacity prior to shooting a well etrating all units of the Cambrian-Ordovician aqui- is about 7.1 gpm/ft in areas where the Glenwood-Peter Sandstone is 200 feet thick. The average cific capacity prior to shooting a well penetrating 350 of the Mt. Simon aquifer and open to all units of Cambrian-Ordovician aquifer is 10.4 gpm/ft.

ZOMETRIC SURFACE

he water levels in 240 deep sandstone wells in north-ern Illinois were measured during the last week in ober and the first week in November, 1960. Data for s in DuPage County are given in table 19. A piezometric surface map for the Cambrian-Ordovician aquifer in northeastern Illinois based on data collected in 1960 was presented in State Water Survey Circular 83, and the piezometric surface for DuPage County in figure 72 was prepared from the regional map.

e 19. Water Levels in Deep Sandstone Wells in 1960

Well umber	Owner	Depth of well *(ft)*	Surface elevation	Depth to water *(ft)*	Water level elevation	Date of measurement 1960
1E-13.4b	C.M.St.P.& P. R.R.	1378	671	510	161	11/3
1E-13.8el	Village of Bensenville	1445	670	520	150	10/4
1E-14.4e	Village of Bensenville	1445	670	514	156	10/4
1E-31.5b	Village of Lombard	1793	738	528	210	11/9
1E-35.5e	City of Elmhurst	1476	703	594	109	11/22
E-14.8l	Suncrest Highlands Sewage & Water Co.	1395	750	466	284	5/2
E-2.2f	City of Elmhurst	1502	690	590	100	7/29
E-9.1h	Village of Villa Park	1475	695	558	137	10/24
E-9.2h	Village of Villa Park	2125	699	560	139	6/6
E-10.1h	City of Elmhurst	1360	669	574	95	10/24
E-10.4g6	Ovaltine Food Products	1999	675	552	123	9/30
E-12.8d	City of Elmhurst	1480	677	564	113	6/24
E-1.4d	Public Service Co. of Northern Illinois	1464	740	512	228	10/24
-15.7h	City of West Chicago	1465	746	412	334	10/24
-13.2b3	City of Naperville	1445	680	430	250	9/12
E-3.8al	Argonne National Lab.	1595	673	493	180	11/15

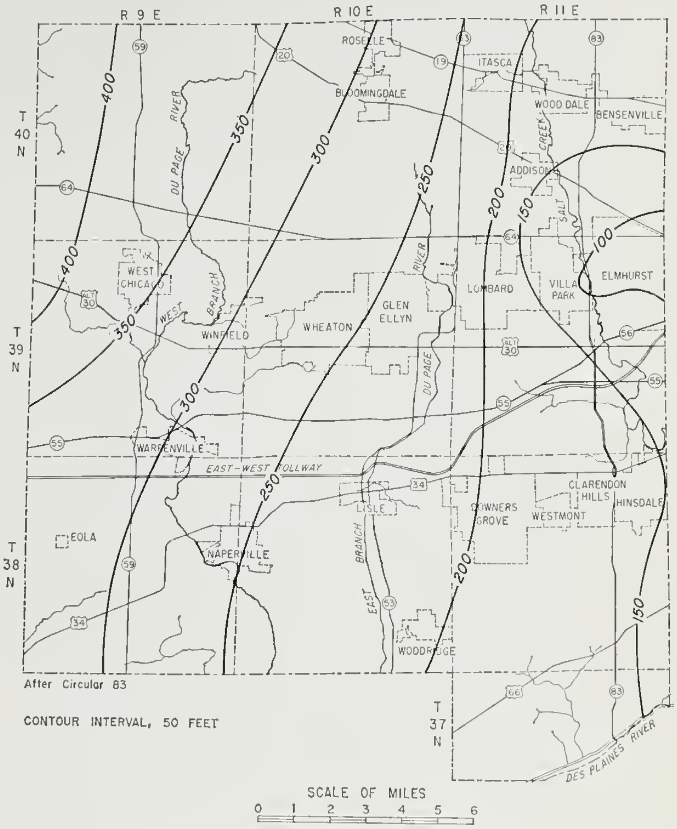


Fig. 72. Elevation of piezometric surface of Cambrian-Ordovician aquifer, October 1960.

The general pattern of flow of water in the Cambrian-Ordovician aquifer beneath DuPage County in 1960 was slow movement from northwest to southeast toward the deep cone of depression centered west of Chicago at Summit. Some of the water flowing toward Chicago is intercepted by pumping centers in the Elmhurst, Villa Park, West Chicago, Naperville, and Argonne areas.

The piezometric surface declines from an average elevation of 430 feet in the northwestern corner of the county to an elevation of about 95 feet east of Elmhurst. The average hydraulic gradient across the county is 19 feet per mile. The piezometric surface was below the top of the Galena-Platteville Dolomite in the deepest parts of the cones of depression at Elmhurst.

WATER LEVELS

Data in Cooperative Report 1 indicate that the average elevation of water levels in deep sandstone wells in

DuPage County was about 730 feet in 1864 prior to heavy well development. By 1960 the artesian pressure had dropped in response to withdrawals of water to elevations of about 334 feet at West Chicago and 95 feet at Elmhurst. In a period of 96 years, water levels at Elmhurst declined about 635 feet or at a rate of about 6.6 feet per year. The total decline and average rate of decline in artesian pressure at West Chicago, 1864 to 1960, were 396 feet and 4.1 feet per year, respectively.

Figure 73 shows the decline of water levels in the Cambrian-Ordovician aquifer, 1864 to 1960. The lines representing decline closely conform in most areas to the 1960 piezometric surface contours. The greatest declines, amounting to more than 600 feet have occurred in the Elmhurst area. The decline has been least in the northwest corner of the county. The average decline over the county was about 480 feet.

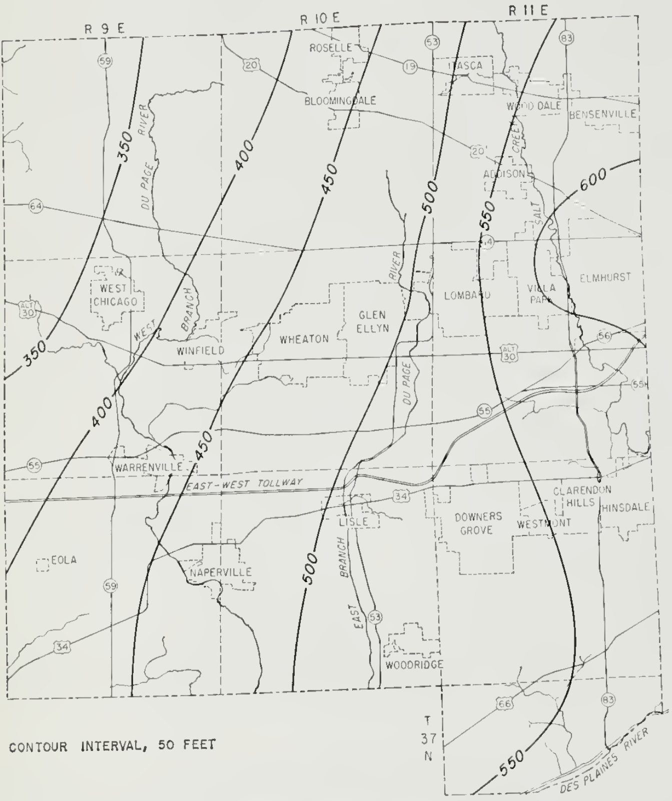


Fig. 73. **Decline of artesian pressure in Cambrian-Ordovician aquifer, 1864-1960.**

Examples of long-term fluctuations in water levels are shown in figure 74. Hydrographs of observation wells in the Cambrian-Ordovician aquifer show a steady decline of water levels largely as a result of the continued increase of withdrawals by municipalities, industries, institutions, and commercial establishments.

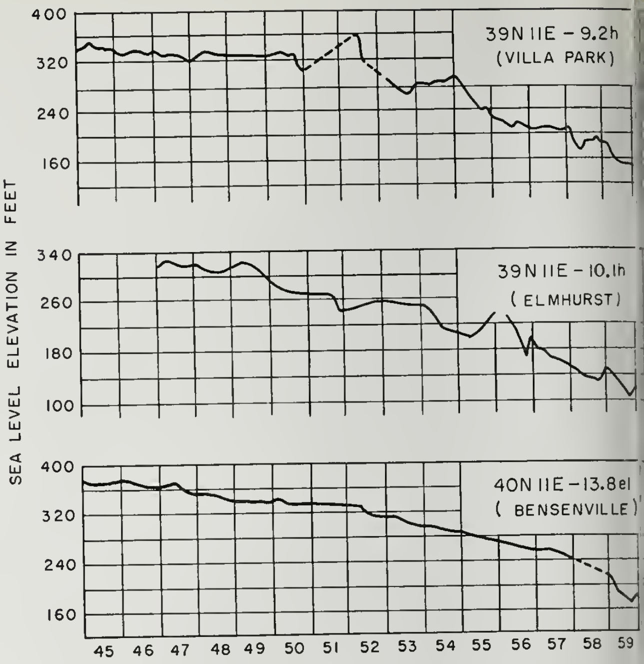


Fig. 74. **Water levels in deep sandstone wells at Villa P Elmhurst, and Bensenville, 1945-1960.**

From 1947 through 1960, the average annual decl in water levels ranged from 15.7 feet in the Elmhu area to 13.2 feet in the Villa Park area. Total decl in artesian pressure, 1947 through 1960, was about feet at Bensenville and Elmhurst and 180 feet at V Park. The average decline in the Elmhurst area, O ber 1958 to October 1959, was about 41 feet; the aver decline, October 1959 to October 1960, was about 12 f

Practical Sustained Yield

Factors affecting the practical sustained yield of Cambrian-Ordovician aquifer in the Chicago reg were discussed in detail in Cooperative Report 1. practical sustained yield is largely limited by the at which water can move from recharge areas eastw through the aquifer to pumping centers, and is defi as the maximum amount of water that can be withdra without eventually dewatering the Ironton-Gales Sandstone.

In Cooperative Report 1 it was estimated that practical sustained yield of the Cambrian-Ordovi aquifer is about 46 mgd. The practical sustained of the Cambrian-Ordovician aquifer was allotted counties in the Chicago region according to the di bution of pumpage from deep sandstone wells 1960. The practical sustained yield of the Cambr Ordovician aquifer in DuPage County was comp to be 4.3 mgd based on pumpage data.

In 1960 about 15 mgd were withdrawn from the Simon aquifer in the Chicago region. Very littl own about the practical sustained yield of the Mt. non aquifer, however, available geohydrologic data ggest that it is reasonable to assume that the practical tained yield does not greatly exceed present pumpage l is about 15 mgd. The practical sustained yield of Mt. Simon aquifer was allotted to counties in the icago region according to the distribution of wells open in the Mt. Simon aquifer. Based on well construction data and Cooperative Report 1, the practical sustained yield of the Mt. Simon aquifer in DuPage County was computed to be about 2.1 mgd. Total withdrawals from the Cambrian-Ordovician and Mt. Simon aquifers in 1960 (8.8 mgd) exceeds the estimated practical sustained yield of the aquifers (6.4 mgd).

WATER QUALITY

he chemical character and temperature of the und water in DuPage County is known from the lyses of water from 106 wells. The results of the lyses are given in tables 20–22. The constituents ed in the tables are given in ionic form in parts per lion (ppm).

Information collected on the temperature of ground water is also presented in the tables. The temperature of water in 60 wells was measured at the same time as samples of water were collected.

Ground water in DuPage County varies in quality between the different aquifers and also within individual

Table 20. Chemical Analyses of Water from Wells in the Glacial Drift Aquifer
(Chemical constituents in parts per million)

Vell mher	Owner	Depth *(ft)*	Date of collection	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Alkalinity	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Hardness as ($CaCO_3$)	Dissolved solids
1E-	Argonne National Lab.	15	11/2/48	13.1	10.8	....	56.6	99.7	38.4	524	80.2	19.0	0.6	557	667
0E-1.8a	K. A. Offerman	77	7/14/36	11.0	0.4	0	101.1	47.2	22.8	306	151.5	21.0	2.8	446	545
0E-15.6h	Snake Hill Spring Inn	38	9/3/36	10.0	0	0	82.4	43.9	1.2	272	98.0	5.0	0.7	387	413
1E-24.2a	American Can Co.	62	2/24/59	......	0.6	0.1	......	......	......	368	......	38.0	1.6	596	790
1E-20.1h	York Center Community Co-op	81	2/8/60	......	1.8	....	......	......	......	344	......	13.0	0.9	480	576
0E-12.5d	Medinah Country Club	68	6/25/56	......	2.5	....	......	......	......	332	......	9.0	....	444	482

Table 21. Chemical Analyses of Water from Wells in the Silurian Dolomite Aquifer
(Chemical constituents in parts per million)

ell nber	Owner	Depth *(ft)*	Date of collection	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Alkalinity	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as ($CaCO_3$)	Dissolved solids	Temperature *(°F)*
1E-8.2h	Argonne National Lab.	345	9/3/48	......	0.4	....	105.7	52.1	22.8	380	131.0	0.6	....	3.6	481	548	52
1E-9.1c	Slovak Catholic Charitable Assoc.	240	12/16/47	......	1.3	....	88.5	49.7	9.9	416	25.1	3.0	....	....	428	453	......
1E-9.8a	Argonne National Lab.	160	8/17/48	......	1.8	....	103.8	60.0	14.5	444	84.7	3.0	....	1.9	510	548	......
E-10.7d	Freund Estate	143	12/16/47	......	9.0	....	86.5	45.8	8.1	364	54.3	1.0	....	....	407	435	......
E-10.7e	Freund Estate	182	12/16/47	......	7.8	....	104.2	60.8	16.6	476	66.4	1.0	....	....	514	559	53.0
E-10.5f1	Argonne National Lab.	310	11/2/48	29.0	1.9	....	92.5	47.6	5.7	404	24.1	4.0	....	0.7	425	451	55.4
E-10.5f2	Argonne National Lab.	284	9/16/48	......	0.2	....	94.4	45.3	20.0	356	98.9	4.0	....	1.9	425	471	52.0
E-10.6f	Freund Estate	158	12/16/47	......	3.1	....	92.8	52.3	7.8	416	45.0	1.0	....	....	450	474	51.0
E-10.6g	Argonne National Lab.	300	8/27/48	......	1.0	....	98.2	45.3	15.0	364	92.4	3.0	....	0.1	434	477	52.0
E-10	Freund Estate	202	12/16/47	......	1.0	....	100.0	58.3	15.2	456	61.5	2.0	....	....	493	523	49.0
-13.2c	City of Naperville	178	4/18/31	14.0	5.0	0	97.5	49.3	0.5	306	127.3	6.0	....	1.5	446	504	......
-23.3g	Lawn Meadow Water Co.	210	6/14/58	16.1	1.5	0.1	86.9	41.9	1.0	288	88.0	8.0	0.1	0.6	390	450	50.8
E-3.8a	Ill. Municipal Water Co.	233	12/16/59	15.4	1.1	Tr	97.7	47.1	12.0	336	111.9	8.0	0.3	0.9	438	491	......
E-11.7c	Oakview Subdiv.	200	4/4/58	16.0	0.3	0	115.6	60.3	12.0	284	234.5	24.0	0.1	0.5	537	646	51.0
E-12.2d	Arthur T. McIntosh Co.	143	6/9/47	19.4	0.2	0.1	97.6	42.2	4.1	284	127.5	7.0	0.2	0.5	418	471	50.3
E-13.8h	Maple Hill Improvement Assoc.	158	11/26/60	10.4	7.4	0	101.0	48.0	21.0	292	147.7	30.0	0.1	9.1	450	574	51.0
E-15.8h1	Benedictine Sisters of the Sacred Heart	300	7/29/36	9.0	0.2	0	64.0	29.8	58.4	300	88.0	12.0	....	3.4	283	433	......
E-16.4d	St. Procopius College	245	8/9/35	11.0	1.0	0	77.6	40.1	7.6	284	80.6	5.0	....	0.9	359	411	......
E-18.3d1	City of Naperville	189.5	6/4/47	17.3	0.2	0	101.2	49.2	4.1	286	160.9	7.0	0.1	0.5	455	518	51.5
E-18.3d2	City of Naperville	202	11/16/37	16.0	Tr	0	70.4	45.0	2.3	252	103.0	3.0	....	2.8	392	405	......
E-1.3a1	Village of Hinsdale	271	6/2/47	24.4	1.6	0	136.9	39.7	20.7	352	181.2	6.0	0.1	3.3	506	631	59.0
E-1.3a2	Village of Hinsdale	210	6/2/47	25.6	Tr	0	141.4	41.9	25.1	356	194.0	8.0	0.2	13.5	526	678	52.1
E-6.4c	Village of Downers Grove	300	1/7/57	13.0	0.8	Tr	90.3	35.3	9.0	272	105.5	7.0	0.2	0.1	371	421	......

Table 21 (Continued)

Well number	Owner	Depth (ft)	Date of collection	Silica (SiO₂)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Alkalinity	Sulfate (SO₄)	Chloride (Cl)	Fluoride (F)	Nitrate (NO₃)	Hardness as (CaCO₃)	Dissolved solids	Te pe tu (°
DUP—																	
38N11E-7.6d	Village of Downers Grove	250	6/3/47	17.9	0.5	0	105.1	48.4	2.5	280	154.5	17.0	0	3.5	462	526	49.
38N11E-8.4b	Village of Downers Grove	291	6/3/47	18.5	Tr	....	122.2	54.2	10.0	340	189.1	9.0	....	0.6	528	621	51.
38N11E-8.7e	Village of Downers Grove	262	12/10/51	16.7	0.3	0.1	125.7	51.1	12.7	336	196.2	9.0	0.2	0.4	525	630	....
38N11E-9.8e	Village of Westmont	316	1/27/55	......	0.1	....	125.7	40.3	29.0	348	182.3	4.0	0.1	....	480	620	....
38N11E-10.7a	Village of Westmont	302	7/14/36	13.0	0.8	0	141.7	36.2	29.9	372	180.4	6.0	....	2.2	504	640	....
38N11E-10.2c	Village of Clarendon Hills	250	5/19/47	23.4	1.5	0	145.2	46.3	25.8	380	215.4	5.0	0.3	0.7	554	687	51.
38N11E-10.6e	Black Hawk Heights Subdiv.	295	6/11/53	20.3	2.7	0.1	142.4	39.4	25.0	352	206.5	3.0	0.3	2.6	518	696	53.
38N11E-10.8e	Village of Westmont	313	1/25/58	20.8	29.0	0.7	129.0	30.4	47.0	360	177.1	3.0	0.4	2.8	448	628	....
38N11E-11.5a	Village of Clarendon Hills	354	9/27/45	15.0	1.7	0	127.5	31.7	21.2	336	149.7	3.0	....	1.5	449	576	51.
38N11E-12.3a1	Village of Hinsdale	273	11/16/37	17.0	0.8	0	135.0	21.5	3.0	240	177.0	3.0	....	4.9	426	542	...
38N11E-12.3a2	Village of Hinsdale	210	11/16/37	16.0	0.2	0	73.4	54.3	6.2	242	163.5	4.0	....	2.8	407	516	...
38N11E-16.1f	Austin Acres Subdiv.	300	9/14/59	16.3	2.9	Tr	118.3	40.7	24.0	340	155.9	8.0	0.4	1.5	463	579	53
38N11E-35.6c	Tri-State Village	200	5/5/58	19.6	1.8	Tr	98.0	38.5	25.0	316	132.1	3.0	0.4	4.0	404	526	51
39N9E-4.4a	City of West Chicago	322	6/26/47	17.3	1.4	0	105.4	54.4	20.2	312	158.0	38.0	0.5	1.0	487	600	51.
39N9E-4.2b	City of West Chicago	310	6/25/50	19.3	0.1	0	83.9	38.9	12.0	296	88.0	4.0	0.6	2.8	370	415	50
39N9E-13.4b	Winfield Sanitarium	198	6/12/39	20.5	0.2	0	85.6	46.8	5.1	318	89.2	4.0	....	2.1	407	472	...
39N9E-13.6c1	Village of Winfield	335	10/17/58	17.0	0.5	0	98.0	53.8	16.0	326	157.2	7.0	0.3	1.4	466	580	51
39N9E-16.6c	City of Wheaton	336	10/3/46	7.9	11.4	0.1	81.2	41.8	17.0	300	101.6	5.0	0.1	0.2	375	447	51.
39N10E-9.6c1	City of Wheaton	341	9/16/59	13.5	1.1	0.1	102.9	43.7	20.0	288	164.8	14.0	0.2	0.6	437	528	51
39N10E-10.3b1	Jefferson Ice Plant	114	6/3/31	18.0	1.8	0	97.0	51.3	8.7	354	100.3	10.0	....	0	453	504	...
39N10E-10.3b2	Jefferson Ice Plant	134	6/3/31	16.0	0.8	0	67.0	36.8	20.9	290	68.7	4.0	....	0.2	319	378	...
39N10E-10.4c	Hathbun Farm Products Co.	138	2/23/44	......	2.1	....	59.7	45.0	22.8	274	99.1	5.0	....	2.2	337	392	51.
39N10E-11.7c1	Village of Glen Ellyn	310	1/16/24	20.8	0.8	0	26.6	29.2	76.7	254	80.6	5.0	....	1.8	......	421	...
39N10E-11.7c2	Village of Glen Ellyn	352	6/16/47	17.4	0.5	0	65.3	30.6	57.0	276	121.8	8.0	....	1.0	290	471	51
39N10E-11.8c	Village of Glen Ellyn	422	12/3/41	13.0	0.7	0	54.5	31.8	29.2	266	109.6	6.0	....	2.0	320	435	...
39N10E-11.3e	Park Commissioners	325	10/21/36	9.0	1.6	0	72.4	3.5	294.0	458	197.8	13.0	....	1.6	44	823	...
39N10E-12.4a	Glen Oak Country Club	202	7/11/39	15.0	1.3	0	109.0	50.4	6.2	334	123.0	14.0	....	1.5	468	859	...
39N10E-12.4c	Glen Oak Country Club	212	7/11/39	17.0	1.9	0	107.5	52.8	19.1	318	160.0	21.0	....	1.7	474	571	...
39N10E-15.8c	Village of Glen Ellyn	422	4/18/58	16.3	0.5	Tr	103.4	35.3	52.0	264	117.7	5.0	0.7	1.4	282	456	51
39N10E-25.4a	W. R. Johnson	160	8/1/38	14.5	3.4	0	102.2	48.1	13.6	360	113.0	3.0	....	1.3	453	530	...
39N10E-35.6g	Valley View Subdiv.	290	6/12/58	16.9	0.9	Tr	72.4	33.2	32.0	304	73.7	3.0	0.3	2.9	318	408	51
39N11E-1.3d	Wendland & Keimel Co.	209	3/2/33	9.0	0.7	0	96.3	48.9	17.5	322	140.0	9.0	....	1.1	442	517	...
39N11E-2.5e	Elmhurst Ice Co.	218	3/2/33	8.0	0.4	0	179.6	83.5	24.6	358	408.0	42.0	....	4.1	793	993	...
39N11E-5.3g	Midland Enterprises	209	3/6/54	......	0.3	....	109.0	38.0	22.8	344	123.8	4.0	....	....	428	542	...
39N11E-7.1h1	Village of Lombard	175	4/17/48	......	2.8	....	107.5	52.1	8.1	336	144.0	6.0	....	1.3	486	507	52
39N11E-7.1h2	Village of Lombard	175	6/7/48	20.7	1.3	Tr	103.4	47.6	8.5	340	122.4	5.0	0.2	0.1	455	510	52
39N11E-8.7h	Village of Lombard	84	5/23/47	23.2	2.1	0.2	112.8	52.9	3.0	324	166.8	6.0	0.3	1.0	500	587	51
39N11E-10.8d1	Village of Villa Park	251	5/21/47	21.4	1.3	0	102.3	43.9	6.0	352	85.8	5.0	0.2	2.1	437	478	53
39N11E-20.1g	Midwest-York Water Co.	241	3/18/58	16.7	4.6	Tr	124.5	49.4	13.0	356	167.4	8.0	0.1	1.4	514	622	...
40N9E-34.1b	Crippled Children's Home	220	11/9/39	20.5	1.2	0	76.2	52.6	6.7	354	54.8	6.0	....	2.6	407	450	...
40N10E-3.4e1	Village of Roselle	182	5/29/47	24.6	0.5	0	68.3	37.9	25.3	212	162.7	1.0	0.5	0.6	327	441	51
40N10E-3.4e2	Village of Roselle	183	12/4/59	19.0	0.7	Tr	66.2	35.4	39.0	228	154.9	4.0	0.4	2.3	311	447	51
40N10E-12.5b	Medinah Country Club	145	3/29/35	10.0	0.8	0	75.6	41.2	15.0	276	115.2	0	....	0.8	358	447	52
40N10E-26.5d	North Glen Ellyn Utility Co.	353	4/23/60	18.2	0.6	0	69.0	29.3	34.0	240	119.9	2.0	0.5	0.8	293	433	...
40N11E-8.4f	Village of Itasca	200	5/16/47	21.4	0.6	0	79.9	41.2	27.8	208	211.3	2.0	0.4	0.8	370	527	52
40N11E-8.8f	Village of Itasca	184	5/16/47	21.8	0.2	0	69.3	38.7	31.3	200	189.7	3.0	0.4	0.7	333	593	52
40N11E-11.8b	G. C. Chambers	150	3/5/34	7.0	2.4	0	246.6	165.0	132.3	48	1457.2	11.0	....	2.7	1295	2157	...
40N11E-15.7g	Martha E. Ruehr	122	7/5/38	10.0	0.8	0	25.3	31.9	46.2	136	148.2	3.0	....	1.1	194	383	...
40N11E-28.7b	Village of Addison	182	1/16/34	11.0	0.5	0	76.7	40.8	24.4	334	68.7	5.0	....	0.9	350	421	...
40N11E-28.3a1	Village of Addison	200	4/28/58	16.0	1.1	Tr	98.0	44.3	22.0	344	112.1	10.0	0.3	0.8	427	525	51
40N11E-28.3a2	Village of Addison	221	1/12/61	......	0.7	....	88.8	44.4	......	340	....	3.0	0.3	1.6	404	450	51
40N11E-28.2f	H. Housermann	108	3/5/34	13.0	1.0	0	102.8	50.6	17.7	352	126.3	12.0	....	4.9	466	545	...
40N11E-28.4f1	Village of Addison	155	5/16/47	24.0	1.4	Tr	108.8	56.7	18.2	326	200.1	6.0	0.2	1.0	505	625	52
40N11E-28.4f2	Village of Addison	115	1/12/61	......	1.3	....	98.2	47.8	......	328	....	3.0	0.3	2.0	442	515	51
40N11E-33.7f	Village of Addison	250	4/28/58	18.0	1.1	Tr	94.4	44.9	12.0	332	106.6	3.0	0.3	0.5	421	495	51
40N11E-36.5d	Emrdy Howard Water Co.	270	4/21/58	16.7	1.4	Tr	87.9	51.5	36.0	368	130.4	4.0	0.3	1.4	432	579	52

aquifers at different geographical locations. The quality of water obtained from any well depends not only on the geological formations penetrated during drilling, but also on the geographical location, the relative productivity of the various formations contributing water to the wells, the artesian pressure of the various formations, and often on the rate of pumping as well as the idle period and time of pumping prior to collection of the sample. In some areas, open and unplugged w may permit water from one aquifer to migrate another aquifer.

GLACIAL DRIFT AQUIFERS

Waters from the glacial drift aquifers are similar mineral content to waters from the Silurian dolom aquifer. The chemical analyses of water from six glac

Table 22. Chemical Analyses of Water from Deep Sandstone Wells
(Chemical constituents in parts per million)

Well umber	Owner	Depth (ft)	Date of collection	Silica (SiO₂)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Alkalinity	Sulfate (SO₄)	Chloride (Cl)	Fluoride (F)	Nitrate (NO₃)	Hardness (as CaCO₃)	Dissolved solids	Temperature (°F)
P—																	
9E-13.2b	City of Naperville	1445	9/9/60	7.2	Tr	0	67.4	24.9	66.0	276	109.2	17.0	1.1	3.7	271	452	57.5
10E-16.3d	St. Procopius College	1208	7/25/35	7.0	0.5	0	76.8	39.0	8.3	286	73.6	5.0	....	1.2	353	380	......
11E-10.8c	Village of Westmont	890	1/13/25	16.1	1.6	0	145.2	22.1	34.8	360	192.0	9.0	....	1.1	......	627	......
9E-4.1a	City of West Chicago	875	5/28/47	19.2	0.7	0	86.4	45.5	16.3	296	111.5	20.0	0.5	0.3	403	478	51.2
9E-10.7f	C.&N.W.R.R.	2083	11/22/30	14.0	0.2	0	79.8	44.0	4.4	302	79.0	4.0	....	1.2	380	419	......
11E-2.2f	City of Elmhurst	1502	6/25/43	12.0	3.4	Tr	135.4	88.2	35.0	359	274.0	12.0	....	0.8	577	755	54.6
11E-4.1d	Village of Villa Park	1419	4/22/58	7.6	0.2	0	80.3	38.5	95.0	272	238.6	33.0	0.6	1.3	360	665	55.4
11E-8.7h	Village of Lombard	2028	5/23/47	12.3	0.3	0	61.3	17.1	71.1	272	70.1	24.0	1.8	1.2	224	439	61.0
11E-9.1h	Village of Villa Park	2123	5/22/47	13.0	0.4	0	60.5	17.7	132.5	304	66.2	99.0	2.6	0.5	224	577	62.5
11E-10.3g	Wander Company	1920	8/15/46	12.0	0.8	0	69.8	17.7	67.6	280	68.3	28.0	....	6.6	247	452	60.0
11E-10.4c	Wander Company	2000	9/19/35	11.0	15.0	0	130.5	53.5	51.5	344	237.2	47.0	....	1.5	544	780	......
11E-10.4g	Wander Company	1900	4/8/36	8.0	Tr	0	62.1	20.2	58.8	242	79.6	30.0	....	0.9	238	433	......
11E-12.8d	City of Elmhurst	1485	2/9/43	16.0	Tr	0	61.0	22.0	43.2	230	80.2	15.0	....	3.6	243	380	59.5
11E-27.8b	Butterfield Country Club	657	2/24/43	16.0	3.0	0	109.3	50.8	6.4	352	131.2	4.0	....	2.9	482	554	51.5
9E-36.6g	Mark Morton	922	7/1/36	12.0	0.8	0	85.0	32.9	20.7	204	123.7	5.0	....	3.1	298	382	......
10E-15.7d	Suncrest Highlands	1395	5/1/58	7.4	0.1	Tr	64.7	29.5	60.0	308	82.9	14.0	1.3	1.9	284	439	53.3
11E-7.1f	Village of Itasca	800	12/15/26	24.0	0.2	0	69.1	37.7	45.3	220	182.1	3.0	....	1.5	327	491	......
11E-13.5b	C.M.St.P.&P. R.R.	1461	1/4/50	12.8	0.5	0	80.4	25.7	50.1	236	147.7	18.0	0.8	1.5	306	476	58.9
11E-13.6c	C.M.St.P.&P. R.R.	2248	6/13/46	13.3	0.2	Tr	48.1	9.5	210.9	228	77.3	218.0	....	0.4	159	722	65.5
11E-13.8e1	Village of Bensenville	1445	11/19/46	12.4	0.7	Tr	73.3	21.8	36.1	244	90.3	10.0	1.0	1.7	274	400	59.5
11E-13.8e2	Village of Bensenville	1442	5/15/47	11.7	0.4	0	71.4	17.9	44.9	272	57.4	13.0	1.2	0.7	252	378	60.0

ft wells in table 20 show iron contents ranging from) 10.8 ppm with a median of 2.7 ppm. Waters from r of the six wells contain more than 0.6 ppm iron. : chloride content ranges from 5 to 38 ppm and rages 17.5 ppm. Of the six samples, four show ride contents above 9 ppm.

he hardness ranges from 387 to 596 ppm and avers 485 ppm. The sulfate content ranges from 80 to ppm with a median of 113 ppm.

ata in Cooperative Report 1 suggest that waters n the glacial drift aquifers have temperatures rangfrom 46° to 54°F.

Silurian Dolomite Aquifer

he hardness of waters from the Silurian dolomite fer ranges from 194 to 1295 ppm and averages 436 n. Waters of less than 300 ppm hardness are found mall areas along the western edge and in northral parts of the county as shown in figure 75. Two l areas of exceptionally hard water, more than) ppm, are indicated. Water with a hardness exceed-500 ppm are concentrated mostly in areas in the rn part of the county. Water from the Silurian mite aquifer has a greater hardness than water the Cambrian-Ordovician aquifer in most areas he county. The pH ranges from 6.2 to 7.6 and ages 7.1.

out 60 percent of 79 samples in table 21 contained than 0.5 ppm iron. The iron content ranges from ce to 29.0 ppm and averages 1.9 ppm. The chloride nt ranges from 0 to 38 ppm with a median of 7.2 . Water from the Silurian dolomite aquifer has an st uniform concentration of 0.3 fluoride.

aters from the Silurian dolomite aquifer con-more sulfates than waters from the Cambrian-

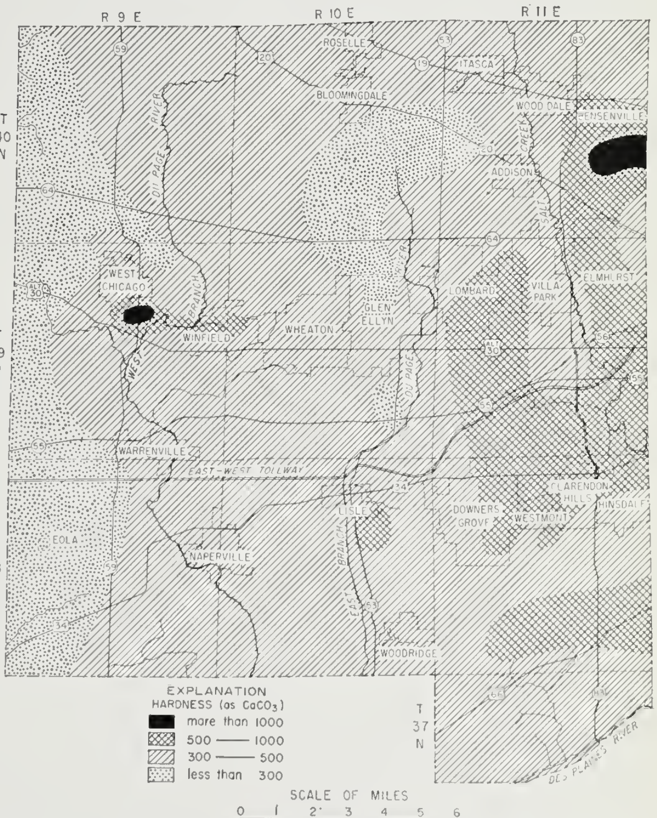


Fig. 75. Hardness of water from the Silurian dolomite aquifer.

Ordovician aquifer. The sulfate content ranges from 24 to 1457 ppm and averages 132 ppm. Waters of less than 100 ppm sulfate are found in large areas in the eastern one-third of the county as shown in figure 76.

The temperature of the water from Silurian dolomite wells ranged from 49° to 59°F and averaged about 52°F.

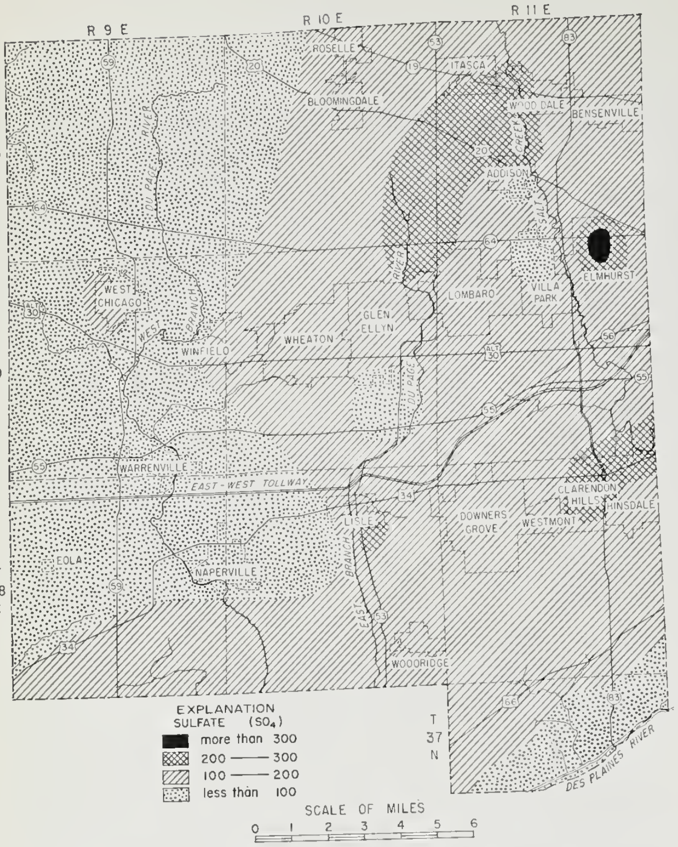


Fig. 76. Sulfate content of water from the Silurian dolomite aquifer.

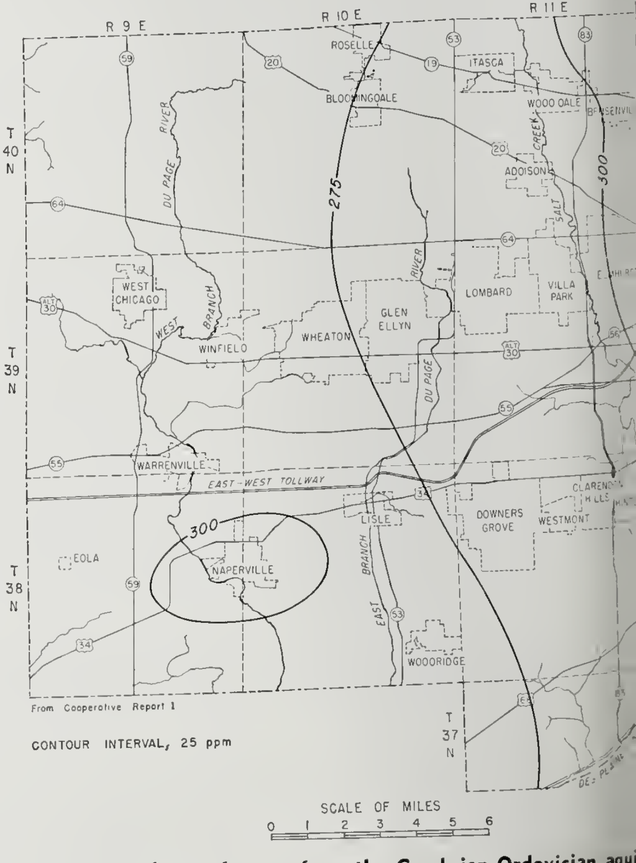
The character and thickness of the unconsolidated glacial drift in part influence the probability of pollution and contamination of the ground water in the underlying Silurian dolomite aquifer. Ground water in the dolomite moves freely through the open network of joints and fractures, and little or no filtration takes place. Once pollution or contamination reaches the dolomite it may travel widely. Filtration of the water which percolates into the dolomite is accomplished best by slowly permeable, clayey glacial till. Coarse-textured materials overlying the dolomite are less effective but do have some filtering action.

The Illinois Department of Public Health recommends that, in closely populated areas, 50 feet of glacial drift must overlie the dolomite if private water supplies are to be used without chlorination. At least 100 feet of glacial drift cover must be present where municipal supplies are obtained. In sparsely populated areas, a minimum thickness of 30 feet of clayey till between the lowest point of the source of pollution and top of the dolomite is necessary before drilling of a well or installation of leaching types of private waste-disposal facilities is recommended.

The map of the thickness of the unconsolidated deposits (fig. 9) shows some areas with less than 50 f of cover above the dolomite. The largest such area in the southwestern part of the county. Most of the areas are beneath ground moraine or valley-train. these areas where the materials are moderate to high permeable, greater thickness of cover may be necessa to filter the water effectively.

Cambrian-Ordovician and Mt. Simon Aquifers

The quality of waters from deep sandstone wells influenced by the proportions of water entering t wells from the various units contributing water to t wells. Waters from the Glenwood-St. Peter and Ironto Galesville Sandstones are in general of similar mine quality. The St. Peter Sandstone tends to have chloride content and hardness higher than water fr the Ironton-Galesville Sandstone. Waters from t Glenwood-St. Peter and Ironton-Galesville Sandsto usually have low iron content (0.2 to 0.4 ppm) and almost uniform concentration of 1.0 ppm fluori Regionally the Galena-Platteville Dolomite is chara terized by high alkalinity (about 350 ppm), low ha ness (less than 100 ppm), absence of sulfates, a usually sufficient hydrogen sulfide to be detected by odor. Water entering deep sandstone wells from t



From Cooperative Report 1

CONTOUR INTERVAL, 25 ppm

Fig. 77. Hardness of water from the Cambrian-Ordovician aqu

urian dolomite aquifer tends to increase the iron tent and hardness of water from these wells. The mary characteristic of the quality of water from the Simon aquifer is its rapid increase in chloride centration with increasing penetration below an vation of —1275 feet. The rate of increase in chloride centration with increasing depth in the aquifer roaches 400 ppm per additional 25 feet of penetra- . The average hardness of water from the Mt. Simon dstone is less than the average hardness of water n the Cambrian-Ordovician aquifer.

s shown in figure 77, the hardness of water from the nbrian-Ordovician aquifer increases to the east from ween 260 and 275 ppm in the western part of the nty to between 300 and 350 ppm in the eastern of the county. The data in table 22 indicate that lness of water from deep sandstone wells ranges n 159 to 577 ppm and averages 322 ppm. The ride content ranges from 3 to 218 ppm and averages ppm. The chemical analyses of water in table 22 v iron contents ranging from a trace to 15 ppm with edian of 1.6 ppm. The pH averages 7.2.

he average sulfate content of waters from the brian-Ordovician aquifer increases rapidly from than 50 ppm in the northwestern corner of the ty to more than 100 ppm in the eastern part of the ty as shown in figure 78. Data in table 22 show that sulfate content of a water from deep sandstone wells es from 57 to 274 ppm and averages 122 ppm.

ata in Cooperative Report 1 indicate that waters the Ironton-Galesville Sandstone range in tem- ture from about 55°F in the western part of the ty to about 58°F in the eastern part of the county. ers from the Glenwood-St. Peter Sandstone are rally about two degrees lower in temperature than rs from the Ironton-Galesville Sandstone. Water the Mt. Simon aquifer appears to increase in temperature by about one degree per 100 feet of additional depth from 66°F at an elevation of 1300 feet.

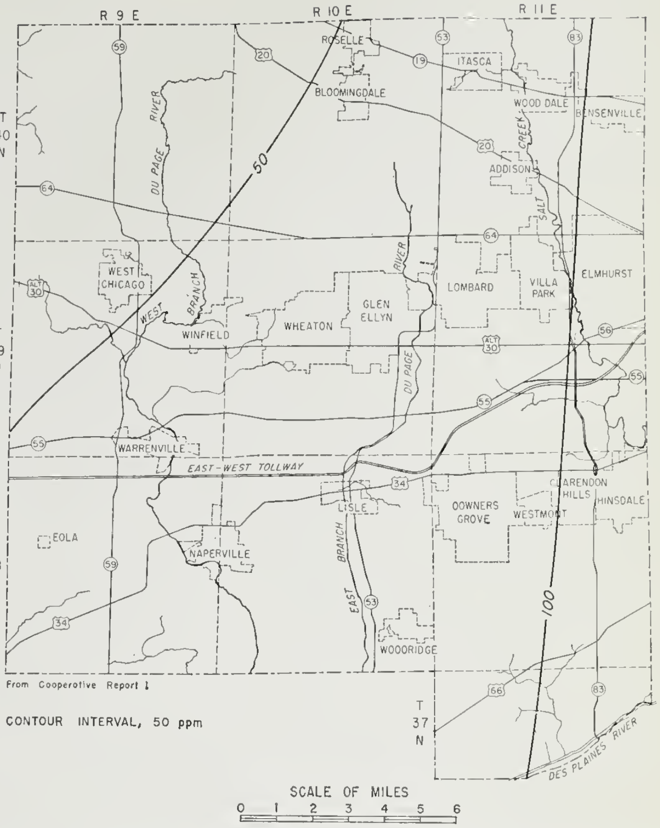


Fig. 78. Sulfate content of water from the Cambrian-Ordovician aquifer.

The temperature of water from deep sandstone wells is influenced by the proportions of water entering the wells from the units contributing water to the well. Temperatures in table 22 range from 51.2° to 65.5°F and average 58°F.

WELL CONSTRUCTION, DEVELOPMENT, AND REHABILITATION

Construction Features of Wells and Pumps

ost wells in DuPage County are drilled by the tool method. Wells in the Silurian dolomite aqui- vith capacities exceeding 100 gpm range in depth 75 to 422 feet and have an average depth of about feet. The wells are usually cased through the un- olidated deposits to bedrock; several wells have rated pipe sections or commercial screens opposite and gravel beds above bedrock. Casing diameters from 4 to 38 inches and commonly exceed 16 s. Bore hole diameters are generally smaller at the m than at the top and finished 8 to 24 inches at the m. Generalized graphic logs of typical wells in the ian dolomite aquifer are given in figure 79A. Details of construction features of selected wells are given in table 23.

Only a few high capacity wells are developed in the glacial drift aquifer. A well at the Medinah Country Club in sec. 12, T40N, R10E is 68 feet deep and has 52 feet 8 inches of 16-inch casing and 15 feet of 16-inch screen. The specific capacity of the well for a pumping rate of 1100 gpm and a pumping period of 24 hours was 41 gpm/ft.

Wells in service in 1960 in the Cambrian-Ordovician and Mt. Simon aquifers range in depth from 1419 to 2219 feet. Wells in the Cambrian-Ordovician aquifer have an average depth of 1450 feet; wells penetrating both the Cambrian-Ordovician and Mt. Simon aquifers have an average depth of 2010 feet. The diameters of bore holes are smaller at the bottom than at the top, commonly ranging from 16 to 30 inches at the top and finished 8 to 12 inches at the bottom. Outer casing diameters generally range from 18 to 30 inches, and inner casings and liners have diameters ranging from 10 to 16 inches. Wells commonly are uncased through many of the formations penetrated, as most of the bedrock encountered does not cave or swell. A drive pipe extends through the unconsolidated deposits to bedrock. The Silurian dolomite aquifer and the Maquoketa Formation are usually cased off. In numerous wells some of the lower units give trouble through caving and these are protected with liners. The lower shales and conglomerates of the Glenwood-St. Peter Sandstone and the weak shales of the upper and middle beds of the Eau Claire Formation often require casing. Occasionally some or all of the Prairie du Chien, Trempealeau, and Franconia rocks are cased off. Generalized graphic logs of typical wells are given in figure 79B. Details of construction features of selected wells are given in table 2

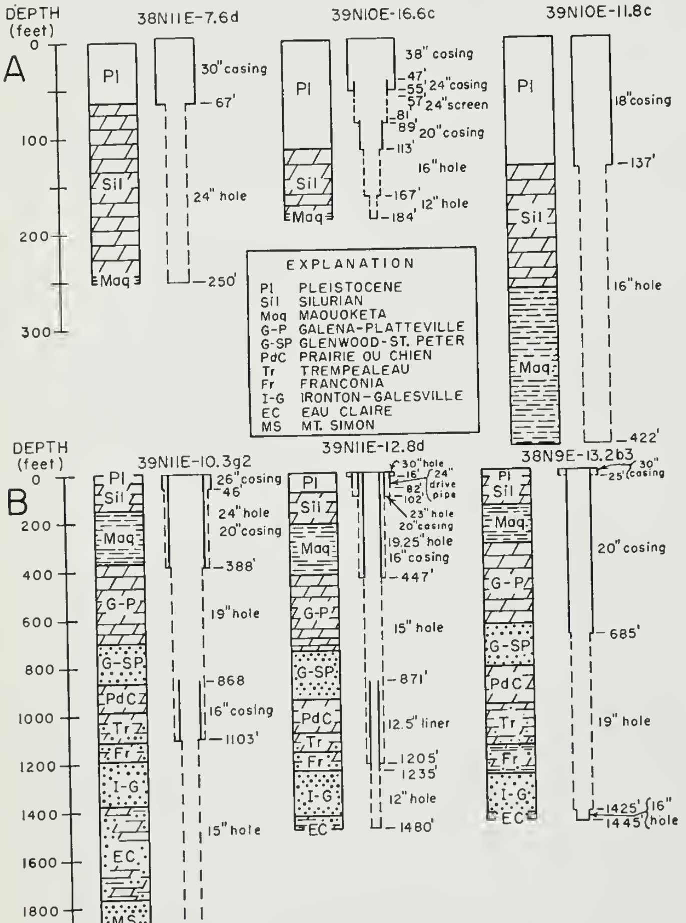


Fig. 79. Construction features of selected wells in Silurian dolomite aquifer (A) and Cambrian-Ordovician and Mt. Simon aquifers (B).

Table 23. Construction Features of Selected Wells in the Silurian Dolomite Aquifer

	Bore hole record		Casing record	
Depth *(ft)*	depth *(ft)*	diam. *(in)*	depth *(ft)*	diam. *(in)*
209	0-42	12	0-42	8
	42-209	8		
271	0-57	20	0-57	20
	57-271	19		
231	0-231	12	0-44	12
			188-231	10
115	0-115	6	0-90	6
85	0-85	4	0-60	4
175	0-62	20	0-62	20
	62-73	18	58-73	18
	73-175	17		
310	0-310	8	0-115	8
352	0-235	12	0-16	12
	235-352	10		
422	0-136	18	0-136	18
	136-422	16		
354	0-354	12	0-127	12
240	0-240	10	0-83	10
250	0-67	30	0-67	30
	67-250	24		
291	0-118	30	0-118	30
	118-291	24		
178	0-44	30	0-44	30
	44-178	24		
190	0-32	30	0-32	30
	32-190	24		
202	0-30	27	0-30	27
	30-202	24		
285	0-285	8	0-58	8
200	0-200	12	0-76	12
313	0-120	16	0-120	16
	120-313	15		
322	0-89	12	0-89	12
	89-322	8		
350	0-116	19	0-116	19
	116-350	15		

Pumps in wells in the Silurian dolomite aquifer wi capacities equal to or greater than 100 gpm are powere by 10 to 100 horsepower electric motors. Pump bow range in diameter from 7 to 15 inches and have lengt ranging from 3.0 to 10 feet. The number of bowl stag ranges from 2 to 15. Column pipes have lengths rangin from 24 to 220 feet and diameters ranging from 5 to inches. Suction pipes have lengths ranging from 10 50 feet and diameters ranging from 4 to 10 inche Over-all lengths of pumps range from 27 to 234 feet a average 145 feet. Details of selected pump installatio are given in table 25.

Pumps in wells in the Cambrian-Ordovician and M Simon aquifers in 1960 were powered by 50 to 400 hors power electric motors. Pump bowls range in diamet from 6 to 15 inches and have lengths ranging from to 19.9 feet. The number of bowl stages ranges fro 8 to 30. Column pipes have lengths ranging from 5 to 810 feet and diameters ranging from 5 to 12 inch Suction pipes have lengths ranging from 10 to 32 f

Table 24. Construction Features of Selected Wells in the Cambrian-Ordovician and Mt. Simon Aquifers

	Bore hole record		Casing record	
Depth (ft)	depth (ft)	diam. (in)	depth (ft)	diam. (in)
2077	0-450	18	0-79	18
	450-1110	12	226-455	16
	1110-2077	10	947-1110	10
1502	0-79	24	0-79	24
	79-460	18	0-89	20
	460-1260	15	0-460	16
	1260-1502	12	744-1260	13
1480	0-16	30	0-82	24
	16-82	24	0-102	20
	82-102	23	0-446	16
	102-446	19	871-1235	12
	446-1205	15		
	1205-1480	12		
2028	0-67	19	0-67	18
	67-264	17	0-264	15
	264-1100	14	245-500	12
	1100-1175	12	1059-1100	12
	1175-2000	10	1077-1175	10
1912	0-76	22	0-445	20
	76-445	20		
	445-1095	15		
	1095-1165	12		
	1165-1912	10		
1445	0-334	12	0-114	12
	334-1060	8	218-334	10
	1060-1445	6	328-785	8
			1060-1163	7
			1163-1269	6

diameters ranging from 5 to 10 inches. Over-all gths of pumps range from 570 to 840 feet and average 694 feet. Details of selected pump installations are given in table 26.

ACID TREATMENT OF WELLS IN DOLOMITE

Acid treatment has been used successfully to develop newly constructed dolomite wells and to rehabilitate old wells. Several wells have been treated with inhibited 15 percent hydrochloric acid in quantities ranging from 600 to 3000 gallons. Treatment is usually performed with the pump and discharge column removed from the well. Acid is introduced through a temporary line extending to a position near the bottom of the well. The solution is allowed to stand under pressure for periods ranging from 30 minutes to 4 days. The pump is reinstalled and the spent acid is removed from the well during pumping periods ranging from 3 to 8 hours.

Well-production tests were made on a few wells before and after acid treatment. The results of the tests are summarized in table 27. There is an extremely wide range (0 to 935 percent) in improvement. Most of the improvements over 100 percent were recorded for rehabilitated wells; improvements generally less than 40 percent were reported for newly constructed wells. In two of the cases where no improvement was observed the acid was allowed to stand for only an hour or less. The results of acid treatment on two wells are shown graphically in figures 46 and 47.

When wells are operated at high rates of pumping the pressure of the water in the Silurian dolomite aquifer

Table 25. Description of Pumps in Selected Wells in the Silurian Dolomite Aquifer

		Pump bowls			Column pipe		Suction pipe		
Horse-power	Rated capacity/head (gpm) (ft)	length (ft)	diam. (in)	Number of bowl stages	length (ft)	diam. (in)	length (ft)	diam. (in)	Over-all length (ft)
30	350/230	4.4	10	5	70	6	10	6	84
15	170/240	7.3	7	15	120	5	10	5	137
15	100/290	6.8	8	13	170	5	....	....	177
15	133/33	....	....	....	......	....	....	....	75
20	500/127	5.6	8	9	130	5	10	5	146
25	500/127	5.6	8	9	130	5	10	5	146
40	900/125	5.8	10	7	112	7	30	6	148
50	1000/126	5.5	14	5	108	10	10	8	123
75	1500/150	5.0	12	4	150	10	10	10	165
50	750/160	8.5	12	9	159	8	20	8	188
60	750/205	3.9	12	3	220	8	10	8	234
15	400/90	4.4	8	5	60	5	10	5	74
20	200/260	3.5	7	5	140	5	10	5	154
25	250/200	4.5	10	5	140	6	....	....	145
25	230/180	4.0	10	4	130	6	30	6	164
10	400/30	3.0	12	2	24	8	....	....	27
40	400/210	10	12	8	50	8	20	8	80
60	600/170	7.8	15	10	79	8	20	6	97
25	400/165	4.5	10	5	160	8	15	8	180
100	840/250	6.0	14	7	88	10	10	10	104
50	1040/170	4.5	15	4	139	10	20	10	164
50	600/205	6.2	15	8	119	10	20	6	145
25	250/280	6.5	10	8	160	6	30	6	197
20	300/130	3.3	8	4	147	6	13	6	163
30	300/230	5.3	8	8	150	6	50	6	205
60	1000/144	4.5	15	4	125	5	35	10	205
60	1000/144	4.5	15	4	160	12	35	10	200

Table 26. Description of Pumps in Selected Wells in the Cambrian-Ordovician and Mt. Simon Aquifers

Horse-power	Rated capacity/head (gpm) (ft)	Pump bowls length (ft)	Pump bowls diam. (in)	Number of bowl stages	Column pipe length (ft)	Column pipe diam. (in)	Suction pipe length (ft)	Suction pipe diam. (in)	Over-all length (ft)
50	136/590	12.7	6	30	590	5	20	5	623
75	325/575	.....	6	10	602	5	....	....	......
100	450/615	10.7	10	16	610	8	10	8	631
125	665/549	10.7	10	16	600	8	10	8	621
125	440/515	10.0	10	14	550	8	10	10	570
150	600/703	15.2	12	17	680	8	10	8	705
200	800/670	12.6	12	12	660	8	32	8	705
200	900/618	12.6	12	12	660	8	20	8	693
200	800/700	19.9	12	23	680	8	10	8	710
200	900/715	12.7	12	11	650	8	....	....	672
250	800/785	14.4	12	14	780	10	20	10	814
250	1000/650	8.9	14	8	650	10	10	10	669
250	1250/660	10.5	12	11	660	10	10	8	680
250	1000/640	12.7	12	11	650	8	....	....	673
300	1200/710	9.7	14	10	690	10	24	10	724
300	1025/680	11.3	12	12	680	10	20	8	711
300	1000/885	18.7	15	18	699	8	30	10	748
300	1000/770	13.8	12	13	620	8	....	....	644
350	1400/720	9.8	14	9	810	10	20	10	840
350	1400/720	9.8	14	9	780	10	20	10	810
250	1000/644	15.5	15	15	620	10	30	10	666
400	1200/740	15	15	14	609	12	31	10	655

is greatly reduced, carbon dioxide is liberated, and the water is unable to hold in solution its load of mineral salts. Consequently calcium carbonate is precipitated in the openings of the well wall and the permeability of the well wall is greatly reduced. This clogging is particularly noticeable in wells with pumping levels below the top of the aquifer. The yields of clogged wells can often be restored to their original value by acid treatment.

During the construction of many dolomite wells some very fine drill cuttings invariably infiltrate a short distance into the water-yielding openings of the aquifer and reduce the permeability of the well wall. A newly completed well is often less than 100 percent efficie because of this partial clogging of openings. The yie of a newly completed well can therefore be increas by removing, by acid treatment, the fine materials whi have migrated into the formation.

Acid introduced into a dolomite well tends to fl into, and widen, fractures leading into the well bo Also the acid reacts with drill cuttings in openings a the dolomite of the well wall. The effect of the reacti with the dolomite of the well wall is to increase t radius of the well bore. Large increases in the radi of a well bore result in comparatively small increas in specific capacity of the well because the speci

Table 27. Results of Acid Treatment of Wells in the Silurian Dolomite Aquifer

Well number	Owner	Depth (ft)	Diam. of well (in)	Quantity of acid used (gal)	Length acid left in well (hr)	Date of acid treatment	Before acid treatment pumping rate (gpm)	Before acid treatment specific capacity (gpm/ft)	After acid treatment pumping rate (gpm)	After acid treatment specific capacity (gpm/ft)	Percent improvement in specific capacity	Remarks (R = rehabilitat N = new)
DUP—												
38N9E-13.2h	City of Naperville	178	24	....	336	12/43	250	4.2	1000	43.5	935	Well No. 4,
38N10E-18.3d1	City of Naperville	190	24	3000	24	4/42	390	3.7	825	20.0	441	Well No. 5,
38N10E-18.3d2	City of Naperville	202	24	1000	½	2/47	285	1.7	285	1.7	none	Well No. 6,
38N10E-18.3d2	City of Naperville	202	24	3000	96	3/48	285	1.7	570	12.5	635	Well No. 6,
39N9E-4.2b	City of West Chicago	310	24	3000	....	4/56	375	3.3	800	10.0	203	Well No. 3,
39N10E-12.4c	Glen Oak Country Club	212	16	600	....	3/57	311	2.2	450	6.3	187	Well No. 2,
39N11E-4.1f	Village of Villa Park	235	12	1500	1	11/59	175	1.8	200	1.8	none	Well No. 5,
39N11E-10.8e2	Village of Villa Park	285	8	1500	....	4/48	200	3.4	369	4.5	33	Well No. 3,
39N11E-13.3g	City of Elmhurst	290	8	3000	....	7/59	335	3.9	300	5.4	39	Well No. 7,
40N10E-3.4f	Village of Roselle	182	10	1000	24	3/55	140	2.3	170	7.7	235	Well No. 1,
40N11E-8.5f1	Village of Itasca	181	20	1000	...	7/59	75	0.7	50	0.4	none	Well No. 6,
40N11E-8.6b	Village of Itasca	190	12	1000	20	4/59	156	1.2	250	3.8	216	Well No. 5,
40N11E-8.6b	Village of Itasca	190	12	2000	72	5/60	250	3.8	400	6.3	66	Well No. 5,

pacity varies with the logarithm of $1/r^2$. Computa-ns made with equations 2, 3, and 4 indicate that a -inch diameter well has a specific capacity about 8 rcent more than that of a 16-inch diameter well. veral thousand gallons of acid cannot dissolve in a y enough bulk dolomite to substantially increase the lius of the well bore. Thus, large increases in the ld of a dolomite well cannot be attributed to well e enlargement. However, the acid will penetrate nsiderable distances along the fractures and will den them and increase their permeability. In addi-n, the acid will dissolve drill cuttings in openings l increase the permeability of the well wall.

The effect of treatment will vary according to the meability of the well wall before treatment. A tight omite with narrow openings will respond differently n one with openings of appreciable width. Further-re, a formation that has been partially clogged dur- drilling will respond differently than one which has been clogged.

ccording to Muskat (1946), acid treatment will be tively effective if the dolomite has extended frac-es or is partially clogged near the well bore. Increases to about 50 percent for wells of initially moderate high capacity may be explained on the assumption t the width of water-yielding openings of a small ial zone about the well bore have been increased /or that drilling cuttings partially clogging the well l have been removed. Moderate increases, 50 to 500 cent, may be explained on the assumption that there extended fractures in the dolomite which are pene-ed and widened by the acid and/or that mild gging was the principal factor in determining the ial yield of the well. Wells of initially low capacity n react best to acid treatment. Increases larger than 500 percent can only be explained on the assumption that there are extended fractures in the dolomite which are penetrated and widened by the acid and/or that there was initially a condition of almost complete clogging of the well wall.

Shooting Wells in Sandstone to Increase Yields

Successful use of explosives to develop newly constructed deep sandstone wells or to rehabilitate old wells has been made in the county. Shooting is normally accomplished with liquid or solidified nitroglycerine. Shots of approximately 100 to 600 pounds of 80 to 100 percent nitroglycerine are usually exploded opposite the most permeable zones of a formation. Shots are often exploded opposite the lower 80 feet of the Ironton-Galesville Sandstone and occasionally opposite the middle 80 feet of the St. Peter Sandstone. Shots are commonly spaced vertically 20 feet apart. The explosions loosen a few cubic feet to several hundred cubic yards of rock that have to be bailed out of the well.

According to Walton and Csallany (1962), the yields of newly constructed deep sandstone wells are increased by shooting because 1) the hole diameters of well bores opposite zones which have been shot are enlarged, and 2) fine drill cuttings and mud deposited in the well wall during construction are removed. Expected average increases in the yields of newly completed wells uncased in the various units or aquifers are listed below.

Units or aquifers uncased in well	Average increase in specific capacity due to shooting, in percent
Galena-Platteville, Glenwood-St. Peter	38
Cambrian-Ordovician	22
Ironton-Galesville	30
Cambrian-Ordovician, Mt. Simon	25

SUMMARY

uPage County is one of the areas in northeastern nois experiencing rapid municipal and industrial wth as development of the suburban area of the city Chicago expands westward. An increase of 102.8 cent in the population of DuPage County during interval between 1950 and 1960 has been concen-ed in the urban areas, and in 1960 these areas con-ed about 85 percent of the population. A shift in economy from agriculture to manufacturing is ng place and farms are becoming fewer while busi- and manufacturing establishments are rapidly in-sing in number. To date, ground-water supplies been adequate to meet the demands of this great nsion; however, problems in water supply are an-pated. Evaluation of the ground-water resources of DuPage County provides a basis for their efficient development and management.

The rocks which form the ground-water reservoir are grouped into geohydrologic units including the principal aquifer units: 1) glacial drift aquifers; 2) Silurian dolomite aquifer; 3) Cambrian-Ordovician aquifer, of which the Ironton-Galesville Sandstone is the most productive unit; and 4) the Mt. Simon aquifer, consisting of the Mt. Simon Sandstone and the lower sandstone of the Eau Claire Formation.

Glacial drift aquifers are made up of deposits of sand and gravel which occur erratically throughout the unconsolidated glacial drift which overlies the bedrock. Three general groupings of glacial drift aquifers are recognized on the basis of their mode of occurrence:

1) surficial, 2) interbedded, and 3) basal. The surficial glacial drift aquifers occur just below land surface, the interbedded aquifers are separated from the surficial and basal aquifers by deposits of till, and the basal aquifers occur at the base of the drift directly above the dolomite.

The Silurian dolomite aquifer is the most heavily developed source of ground water in the bedrock and is considered in most detail in this report. This aquifer includes rocks of the Niagaran and Alexandrian Series and occurs immediately below the unconsolidated material throughout most of the county. Thickness of the Silurian dolomite aquifer reaches a maximum of about 250 feet. Joints, fractures, and solution cavities influence strongly the occurrence, movement, and availability of ground water in the Silurian dolomite aquifer. The weathered zone with solution-enlarged openings in the upper part of the dolomite directly beneath the bedrock surface is believed to be a major water-yielding zone.

Large ranges in the yields of wells in the Silurian dolomite aquifer suggest that major differences exist in its water-yielding properties. Many aspects of the lithologic, structural, and topographic character of the dolomite influence its capacity to yield water. Statistical analysis establishes significant relationships between specific capacity of wells and 1) thickness of the Silurian dolomite aquifer at the well site, 2) thickness of the Niagaran Series penetrated by the well, and 3) thickness of reef penetrated by the well.

On the basis of a frequency analysis of specific capacities of wells versus deepest stratigraphic unit penetrated by wells, two units of geohydrologic significance are recognized within the Silurian dolomite aquifer: 1) the Niagaran aquifer, and 2) the Alexandrian aquifer. The weathered zone with solution-enlarged openings in the upper part of the dolomite occurs in each of these aquifers where they directly underlie the glacial drift. Locally, the shaly basal beds of the Niagaran Series restrict recharge to the underlying dolomite and are considered as a separate unit (the basal unit of the Niagaran aquifer).

The glacial drift and Silurian dolomite aquifers are connected hydrologically and are separated from the Cambrian-Ordovician aquifer by the shales of the Maquoketa Formation. The relatively impermeable parts of the Eau Claire Formation hydrologically separate the Cambrian-Ordovician aquifer from the underlying Mt. Simon aquifer.

Total pumpage from wells has increased steadily at an accelerating rate since the first wells were drilled in 1890. During the 70-year period, 1890 to 1960, total pumpage from all aquifers increased from 841,000 gpd to 29.3 mgd at an average rate of increase of about 410,000 gpd per year. Of the total water pumped from wells in 1960, 68 percent was derived from the Siluri dolomite aquifer, 30 percent from the Cambrian-Ord vician and Mt. Simon aquifers, and 2 percent from t glacial drift aquifers.

A comparison of Silurian dolomite aquifer wat level hydrographs and pumpage graphs indicates that general water-level decline is directly proportional pumpage and suggests that recharge balances discharg

Controlled pumping tests were made in two areas DuPage County to determine the hydraulic properti of the Silurian dolomite aquifer and its confining bed The average coefficient of storage and the leaka coefficient were calculated to be about 0.0002 a 3.7×10^{-3} gpd/cu ft, respectively. The coefficient transmissibility varies considerably due to the variab thickness of the dolomite aquifer; however, based up 115 well production tests the regional average coefficie of transmissibility is about 100,000 gpd/ft.

Specific capacity frequency graph analysis for dol mite units penetrated by wells indicates that the Nia aran and Alexandrian Series are more productive tha the Maquoketa Formation, and the Niagaran Series more productive than the Alexandrian Series. The pr ductivity of the Alexandrian Series is the most co sistent and that of the Maquoketa Formation is th least consistent.

Data on the response of the Silurian dolomite aquif to heavy pumping and data on yields of existing produ tion wells indicate that the potential yield of the Sil rian dolomite aquifer is limited by recharge. Calculate recharge rates are based upon measured areas of infl ence and pumpage data. The potential yield of th Silurian dolomite aquifer is estimated to be about 3 mgd based on the recharge rates.

In 1960, nonpumping water levels were not critic in any pumping center and there were areas in th county unaffected by pumping. The practical sustaine yield of existing pumping centers exceeded total with drawals in 1960. The practical sustained yield of th Silurian dolomite aquifer is computed to be about 3 mgd based upon critical water-level and rate of re charge data. Thus, nearly all the potential yield o the Silurian dolomite aquifer can be developed wit scattered production wells in existing pumping center About 3 mgd is beyond existing pumping centers mostl in areas in the northwestern and southwestern part of the county.

Extrapolation of pumpage growth curves of pumpin centers shows that the practical sustained yields of sev eral pumping centers will probably be exceeded withi 2 to 5 years and the practical sustained yields of a pumping centers will be exceeded by 1985. An extrapo lation of the pumpage growth curve for the count suggests that the total withdrawals from wells in th ian dolomite aquifer will exceed the potential yield bout 1977.

ll development of the Silurian dolomite aquifer assumed in estimating its potential and practical ined yields, thus the glacial drift may be considered upplementing the Silurian dolomite aquifer yield. ydrographs of the water levels in the glacial drift show a pattern of seasonal fluctuation similar to, affected to a greater degree than, the hydrographs ater levels of wells completed in the Silurian dolomite aquifer. The hydrographs indicate no general or anent decline in water levels.

e potential yield of the glacial drift aquifers is ated to be about 3 mgd based upon studies of m flow data, recharge rates of the Silurian dolomite fer, where applicable, and by assuming full development of the Silurian dolomite aquifer and supplemental opment of the glacial drift aquifers. In many , full development of glacial drift aquifers and lemental development of the Silurian dolomite aquifer ay be advantageous. Thus, it is possible to obtain water from the glacial drift aquifers than com- d and correspondingly less water from the Silurian ite aquifer. The potential yield of the glacial drift ers (3 mgd) greatly exceeds withdrawal from drift (0.52 mgd) in 1960.

ring the period 1943 to 1954, seven pumping tests made in DuPage County to determine the hy- ic properties of the Cambrian-Ordovician aquifer. cients of transmissibility range from 14,700 to gpd/ft and average 18,000 gpd/ft. The average ient of storage is estimated to be about 0.00035 on data in Cooperative Report 1.

e general pattern of flow of water in the Cambrian- vician aquifer beneath DuPage County in 1960 was movement from northwest to southeast toward the cone of depression centered west of Chicago at nit. The piezometric surface declines from an ge elevation of 430 feet in the northwestern corner county to an elevation of about 95 feet east of urst.

a in Cooperative Report 1 indicate that the average elevation of water levels in deep sandstone wells in DuPage County was about 730 feet in 1864 prior to heavy well development. By 1960, the artesian pressure had dropped in response to withdrawals of water to elevations of about 334 feet at West Chicago and 95 feet at Elmhurst. In a period of 96 years, water levels at Elmhurst declined about 635 feet or at a rate of about 6.6 feet per year. The total decline and average rate of decline in artesian pressure at West Chicago, 1864 to 1960, were 396 feet and 4.1 feet per year, respectively.

Factors affecting the practical sustained yield of the Cambrian-Ordovician aquifer in the Chicago region are discussed in detail in Cooperative Report 1. The practical sustained yield of the Cambrian-Ordovician aquifer in DuPage County was computed to be about 4.3 mgd based on pumpage data.

Based on well construction data and Cooperative Report 1, the practical sustained yield of the Mt. Simon aquifer in DuPage County was computed to be about 2.1 mgd. Total withdrawals from the Cambrian-Ordovician and Mt. Simon aquifers in 1960 (8.8 mgd) exceeded the practical sustained yield of these aquifers (6.4 mgd).

Temperatures in the glacial drift aquifers range from 46° to 54°F. The hardness averages 485 ppm. The temperature of water in the Silurian dolomite aquifer ranges from 49° to 59°F and averages about 52°F. Hardness ranges from 194 to 1295 ppm and averages 436 ppm. Water with hardness exceeding 500 ppm is concentrated mostly in the eastern parts of the county.

The temperature of water from the Cambrian-Ordovician aquifer ranges from about 53° to about 58°F. The hardness ranges from less than 100 ppm to slightly more than 500 ppm.

Water from the Mt. Simon aquifer appears to increase in temperature by about one degree per 100 feet of additional depth below a depth of 2000 feet where the temperature is 66°F. The primary characteristic of the quality of water from the Mt. Simon aquifer is the rapid increase in chloride concentration with depth. At depths below 2000 feet, water from the Mt. Simon aquifer is too highly mineralized for most purposes.

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APPENDIX A

SELECTED WELL RECORDS

Wells listed below can be identified by the well numbering system described on page 8.

Abbreviations used in this table are:

DUP = DuPage County
SS = State Geological Survey sample set number
DL = Driller's Log
TB = Test Boring
P = Public Supply

I = Industrial Supply
R = Rural (non irrigation) Supply
Dr = Drift
Sil = Silurian
Maq = Maquoketa
C-O = Cambrian-Ordovician

G-P = Galena-Platteville
G-SP = Glenwood-St. Peter
Tr = Trempealeau
EC = Eau Claire
MS = Mt. Simon
Dol = Dolomite

Well number	Owner (*well designation*)	Year drilled	Surface elevation (*ft above sea level*)	Depth (*ft*)	Deepest formation reached	Main aquifer	Type of record	Use
DUP—								
37N11E-3.8a1	Argonne National Lab. #1A	1950	675	1595	EC	C-O	SS 19957 DL	I
37N11E-4.3b	Argonne National Lab. #4	1959	710	340	Maq	Sil Dol	SS 33160 DL	I
37N11E-8.2h	Argonne National Lab. #5	1948	751	345	Maq	Sil Dol	SS 18447 DL	I
37N11E-10.5f	Argonne National Lab. #1	1948	675	284	Maq	Sil Dol	SS 18445 DL	I
37N11E-10.6g	Argonne National Lab. #2	1948	663	330	Maq	Sil Dol	SS 18445 DL	I
37N11E-17.2g	Argonne National Lab. #4	1955	748	181	Sil	Sil Dol	SS 26122 DL	I
38N9E-1.5e	Northern Ill. Toll Rd #5A	1959	730	41.5	Dr	....	SS 321000	TB
38N9E-2.1h	Elmhurst-Chicago Stone Co. #1	1957	690	265	Sil	Sil Dol	SS 30711 DL	I
38N9E-4.5c	Northern Ill. Toll Rd #8B	1959	710	66.5	Dr	....	SS 32347	T
38N9E-5.4a	Commonwealth Edison #111	1958	741	200	Maq	Sil Dol	SS 33536	I
38N9E-6.2b	Northern Ill. Toll Rd #2B	1958	732	61.5	Dr	....	SS 32348	TB
38N9E-11.3h	R. W. Glassner #1	1940	700	265	Maq	Sil Dol	SS 7074 DL	R
38N9E-13.2b3	Naperville City Well #7	1958	680	1445	EC	C-O	SS 30726 DL	P
38N9E-15.6f	Concrete Products Inc.	1959	702	141	Sil	Sil Dol	SS 34783 DL	R
38N9E-15.7d	Pioneer Publishing Co.	1961	704	1000	Tr	G-SP/Tr	SS 41237	I
38N9E-15.7f	Concrete Products Co. #1	1959	702	128	Sil	Sil Dol	SS 34782	I
38N9E-17.8c2	Warren Petroleum Co. #2	1953	717	282	Maq	Sil Dol	.... DL	I
38N9E-21.2e	Harry Gregory	1949	709	70	Sil	Sil Dol	SS 19822 DL	R
38N9E-23.3g	Lawn Meadow Water Co.	1956	659	210	Maq	Sil Dol	SS 33417 DL	P
38N9E-24.8d	W. M. Bender #1	1959	700	100	Sil	Sil Dol	.... DL	R
38N10E-1.1g	Morton Arboretum Drug Plant	1945	720	250	Maq	Sil Dol	SS 15341 DL	I
38N10E-3.2f	Northern Ill. Toll Rd #2	1958	678	35	Dr	....	SS 31685	T
38N10E-3.8a	Ill. Municipal Water Co. #2	1959	723	233	Maq	Sil Dol	DL	P
38N10E-3.8b	Richard Schmoker	1941	712	124	Sil	Sil Dol	SS 6713 DL	R
38N10E-5.2a	J. B. Slifer	1944	760	123	Sil	Sil Dol	SS 11826 DL	R
38N10E-5.4d	Northern Ill. Toll Rd #5B	1959	780	42	Dr	Sil Dol	SS 32102	T
38N10E-5.6d	Northern Ill. Toll Rd #3	1958	768	31.5	Dr	....	SS 31836	T
38N10E-7.3e	Peter DuHai	1941	738	97	Sil	Sil Dol	SS 6712 DL	R
38N10E-9.2c	Harrison & Grace R.	1943	700	93	Sil	Sil Dol	SS 10210 DL	R
38N10E-11.7c	Oakview Subdivision #1	1957	743	200	Sil	Sil Dol	SS 27990 DL	P
38N10E-12.2b	Belmont Highwood	1954	738	295	Maq	Sil Dol	SS 23830	P
38N10E-13.2d	Rietz Construction Co. #22	1959	754	165	Sil	Sil Dol	.... DL	R
38N10E-15.8h2	Sacred Heart Academy #2	1937	720	237	Maq	Sil Dol	SS 2202 DL	P
38N10E-16.4d	St. Procopius College #2	1935	734	245	Maq	Sil Dol	SS 1689	P
38N10E-17.8b	John Henry	1950	743	338	Maq	Sil Dol	SS 20299 DL	R
38N10E-18.3d2	Naperville City #6	1937	688	202	Maq	Sil Dol	SS 2173 DL	P
38N10E-19.3e3	E. J. Laky	1942	710	107	Sil	Sil Dol	SS 8679 DL	R
38N10E-19.4e	Harry Hoyle	1939	712	105	Sil	Sil Dol	SS 3958 DL	R
38N10E-21.3d	George Moss	1959	755	104	Sil	Sil Dol	.... DL	R
38N10E-25.5b	Surety Builders Woodridge #3	1958	738	70	Sil	Sil Dol	SS .... DL	T
38N10E-26.1b	Surety Builders Woodridge #2	1958	740	75	Sil	Sil Dol	.... DL	T
38N11E-1.3a1	Hinsdale City Well #2	1924	690	268	Maq	Sil Dol	SS 766 DL	P
38N11E-4.4f2	Liberty Park #2	1956	745	275	Maq	Sil Dol	SS 26960 DL	P
38N11E-6.4c	New Downers Grove Village		755	300	Sil	Sil Dol	SS 26464	..
38N11E-7.8b	Wm. Schaffner	1944	710	100	Sil	Sil Dol	SS 11581 DL	R

Well number	Owner (*well designation*)	Year drilled	Surface elevation (*ft above sea level*)	Depth (*ft*)	Deepest formation reached	Main aquifer	Type of record			Use
11E-8.7e	Tivoli Theater	1941	720	264	Maq	Sil Dol	SS	6714	DL	I
11E-8.7e	Village of Downers Grove	1951	715	268	Maq	Sil Dol	SS	20945	......	P
11E-9.1h	Westmont City Well #2	1926	752	313	Maq	Sil Dol	SS	560	DL	P
11E-10.1e	Clarendon Hills Well #2	1932	730	250	Maq	Sil Dol	SS	1231	......	P
11E-10.6e	Blackhawks Heights Water Supply	1953	740	285	Maq	Sil Dol	SS	23251	DL	P
11E-10.7a	Westmont City Well #3	1935	760	302	Maq	Sil Dol	SS	1687	DL	P
11E-10.8e	Village of Westmont #4	1958	755	313	Maq	Sil Dol	SS	30748	DL	P
11E-11.5b	Clarendon Hills #3	1945	710	354	Maq	Sil Dol	SS	12835	DL	P
11E-11.5d	Clarendon Hills #4	1956	760	370	Maq	Sil Dol	SS	26358	DL	P
11E-15.3c	R. H. Hurd	1943	730	160	Sil	Sil Dol	SS	10032	DL	R
11E-18.2g	James Delany	1943	730	142	Sil	Sil Dol	SS	10151	DL	R
1E-21.1c	Clarendon Hills Cemetery	1935	767	202	Sil	Sil Dol	SS	1694	DL	I
1E-24.3b	Int'l Harvester #1	1956	718	290	Maq	Sil Dol	SS	28040	DL	I
1E-26.5b	H. F. Zitzka	1959	710	165	Sil	Sil Dol			DL	R
1E-27.8d	Brookhaven Manor #1	1957	755	310	Maq	Sil Dol	SS	32256	DL	P
1E-30.5d	Maple Crest Lake Country Club	1958	781	395	Maq	Sil Dol	SS	31003	DL	I
1E-32.6h2	John Firelli #5	1957	755	165	Sil	Sil Dol		....	DL	R
1E-33.2b2	Cass School District	1958	725	250	Maq	Sil Dol	SS	31359	DL	P
1E-34.8c	Frank Fulkenalyer	1946	705	90	Sil	Sil Dol	SS	14453	DL	R
E-2.5c	J. V. Bauer	1942	765	163	Sil	Sil Dol			DL	R
E-3.1h2	Campbell Soup Co. #4	1947	763	248	Maq	Sil Dol	SS	16579	DL	I
E-4.1b	City of W. Chicago #3	1950	768	310	Maq	Sil Dol		....	DL	P
E-4.2e	A. Scola	1943	760	111	Sil	Sil Dol	SS	9886	DL	R
E-4.7f	L. G. Carbary	1943	760	108	Sil	Sil Dol	SS	9881	DL	R
E-5.6g	Western Electric Co. #3	1958	752	268	Maq	Sil Dol	SS	31052	DL	I
E-8.2b	Harry Glasshagel	1942	750	105	Sil	Sil Dol	SS	7707	......	R
E-9.3d	Lindsay Chemical Co.	1953	750	332	Maq	Sil Dol	SS	24589	DL	I
E-9.7d	George Ball Inc.	1958	750	350	Maq	Sil Dol	SS	31318	DL	I
E-10.7f	Chicago Northwestern R.R.	1924	760	2082	MS	C-O/MS	SS	401	DL	I
E-11.2h	Byron Spiers	1942	740	115	Sil	Sil Dol	SS	9882	DL	R
E-13.2b1	Wheaton Park Manor	1955	768	268	Maq	Sil Dol		....	DL	P
E-13.6c	Village of Winfield #2	1957	778	335	Maq	Sil Dol	SS	27666	DL	P
E-23.3a	E. G. Davidson	1942	750	143	Sil	Sil Dol	SS	7705	......	R
E-25.3f	Bernice Acheson	1947	750	130	Sil	Sil Dol		....	DL	R
E-32.4h	Franklin White	1941	745	161	Sil	Sil Dol	SS	6711	DL	R
E-35.1a	Elmhurst-Chicago Stone Co.	1957	709	274	Maq	Sil Dol	SS	30710	DL	I
E-2.3e	Roy Spalding School	1957	720	160	Sil	Sil Dol		....	DL	P
E-2.4h	Bennet Construction Co.	1946	742	350	Maq	Sil Dol	SS	14736	......	P
E-9.2f	City of Wheaton #5	1954	750	341	Maq	Sil Dol	SS	24881	DL	P
E-11.7c	Glen-Ellyn Village #2	1922	760	352	Maq	Sil Dol	SS	1048	......	P
E-12.4c	Glen Oak Country Club #3	1957	700	212	Maq	Sil Dol	SS	28036	......	I
E-12.5a	Glen Oak Country Club	1929	688	202	Maq	Sil Dol	SS	856	DL	I
E-15.1b1	Glen Ellyn Village Well	1954	770	415	Maq	Sil Dol	SS	24581	......	P
E-16.6c3	Wheaton City Well #4	1946	753	350	Maq	Sil Dol	SS	15659	......	P
E-19.4g	St. Francis High School #1	1957	772	252	Maq	Sil Dol	SS	30226	DL	P
E-23.2d	Frederic Babcock	1942	760	130	Sil	Sil Dol	SS	11104	DL	R
E-24.5a	Glen Ellyn Sewage Disp.	1931	685	269	Maq	Sil Dol	SS	1206	DL	I
E-30.1h	Arrow Head Subdivision #1	1959	740	335	Maq	Sil Dol	SS	34398	......	P
E-35.6g	Valley View Subdivision #1	1957	750	290	Maq	Sil Dol	SS	28457	DL	P
E-34.3d	Morton Arboretum #1	1956	748	250	Sil	Sil Dol	SS	26396	DL	..
E-1.8f	Elmhurst City Well #1	1915	678	1480	EC	C-O	SS	4229	DL	P
E-2.2f	Elmhurst City Well #3	1926	690	2077	MS	C-O		....	DL	P
E-4.1f	Village of Villa Park #7	1958	704	1420	EC	C-O	SS	30860	DL	P
E-5.3g	Lombard Heights	1954	722	210	Maq	Sil Dol	SS	24247	DL	P
E-6.3a	Village of Lombard #4	1953	700	2062	MS	C-O/MS	SS	23911	DL	P
E-7.2h	Village of Lombard #3	1949	693	175	Maq	Sil Dol	SS	19637	......	P
E-8.8h2	Village of Lombard #2	1926	696	2038	MS	C-O/MS	SS	627	DL	P
E-9.1h	Villa Park Village Well #1	1928	699	2125	MS	C-O/MS			DL	P
E-9.2h	Villa Park Village Well #2	1931	700	2110	MS	C-O/MS	SS	905	......	P
E-10.1h	Elmhurst City Well #4	1928	665	2205	MS	C-O/MS		....	DL	P
E-10.3g3	Wander Company #11	1933	668	1920	MS	C-O/MS	SS	15336	......	I
E-10.8c2	Villa Park Well #4	1923	702	220	Maq	Sil Dol	SS	128	......	P
E-12.8d	Elmhurst City Well #5	1940	675	1480	EC	C-O	SS	6059	DL	P
E-18.3a	Cambell	1957	720	147	Sil	Sil Dol	SS	32037	......	R
E-20.6g	Midwest York Co.	1954	725	241	Sil	Sil Dol		....	DL	P

Well number	Owner (*well designation*)	Year drilled	Surface elevation (*ft above sea level*)	Depth (*ft*)	Deepest formation reached	Main aquifer	Type of record	Use
DUP—								
39N11E-24.2g	J. Harris Jones	1957	690	350	Maq	Sil Dol	.... DL	
39N11E-24.3a	American Can Co. #2	1959	682	245	Maq	Sil Dol	SS 34076	I
39N11E-27.5h	Ill. Toll Highway	1957	692	238	Sil	Sil Dol	SS 30676 DL	I
39N11E-28.6e	Northern Ill. Toll Rd #3	1958	717	36.5	Dr	....	SS 31568	
40N9E-2.7g	Village of Bartlett #1	1943	786	430	GP	G-P Dol	SS 10076	I
40N9E-3.5b	Golden Valley Homes #1	1959	815	392	Maq	Sil Dol	SS 34610 DL	P
40N9E-5.5c	Leonard Ellis	1947	775	163	Sil	Sil Dol	SS 17687 DL	R
40N9E-29.7a	Howard Aircraft Corp.	1942	753	1006	G-SP	G-SP	SS 9843 DL	I
40N9E-32.2d	Elgin-Joliet-Eastern R.R.	1931	755	1038	EC	C-O	SS 1169 DL	I
40N9E-32.5g	Kawneer Products #2	1959	755	270	Maq	Sil Dol	.... DL	I
40N9E-33.1a	Guy Ross	....	755	150	Sil	Sil Dol	SS 7704	R
40N9E-34.1d	Campbell Soup Co.	1946	730	255	Sil	Sil Dol	SS 26580 DL	I
40N9E-35.3g	Sidwell Studio	1959	748	190	Maq	Sil Dol	SS 33309 DL	I
40N9E-36.2h	Mark Morton #1	1930	790	912	G-SP	G-SP	SS 100336 DL	R
40N10E-3.4e2	City of Roselle #2	1954	770	183	Maq	Sil Dol	SS 24958	
40N10E-8.5e	Ernest Huntington	1959	783	182	Maq	Sil Dol	.... DL	R
40N10E-14.8d2	Suncrest Highlands	1956	722	1395	EC	C-O	.... DL	P
40N10E-17.3d	Roger Seddor	1957	802	235	Maq	Sil Dol	.... DL	R
40N10E-20.5d	Cloverdale Cement Plant #2	1958	767	320	Maq	Sil Dol	SS 31466 DL	I
40N10E-31.2g	Durable Construction Co.	1958	760	335	Maq	Sil Dol	SS 31476 DL	I
40N11E-8.7e	Village of Itasca #4	1951	690	233	Maq	Sil Dol	SS 21782 DL	P
40N11E-11.6a	Village of Bensenville #4	1961	685	1494	EC	C-O	SS 41071 DL	P
40N11E-13.3c	C.M.St.P. & P. R.R. #1	1912	665	2290	MS	C-O/MS	.... DL	I
40N11E-13.4b	C.M.St.P. & P. R.R. #6	1950	672	1461	EC	C-O	SS 20203 DL	I
40N11E-13.8e2	Village of Bensenville #2	1929	672	1442	EC	C-O	SS 956 DL	P
40N11E-14.4e	Village of Bensenville #3	1956	677	1445	EC	C-O	SS 25024	P
40N11E-21.8a	Evangelical Lutheran Orphanage	1938	690	301	Sil	Sil Dol	SS 2855 DL	P
40N11E-23.4d	White Pines Golf Club	1950	687	625	G-P	G-P Dol	SS 20544	I
40N11E-24.4b	River Forest Country Club	1959	665	219	Sil	Sil Dol	SS 34078 DL	I
40N11E-25.5f	Highlands Country Club #1	1959	680	231	Sil	Sil Dol	SS 33412 DL	P
40N11E-35.5e	City of Elmhurst #6	1954	700	1476	EC	C-O	SS 24957	P

APPENDIX B

REFERENCE WELLS AND TEST BORINGS

DUP 38N9E-4.5e

rthern Illinois Toll Road Boring. Drilled 1958 by Soils sting Service. Total depth 66.5 feet. Elevation 710 feet imated from topographic map. Illinois State Geological vey Sample Set 32347. Studied by A. J. Zeizel.

istocene Series	Depth (ft)
ilt, yellowish brown, clayey oxidized, noncalcareous	1.0 to 2.5
ilt, yellowish brown, oxidized, slightly calcareous, *Tasmanites*	3.5 to 5.0
ame	6.0 to 7.5
ilt, light grayish brown, laminated, calcareous, *Tasmanites*	8.5 to 10.0
ilt, grayish brown, laminated calcareous, *Tasmanites*	11.0 to 12.5
ame	13.5 to 15.0
ame	16.0 to 17.5
ame	18.5 to 20.0
ame	20.0 to 21.5
ill, grayish brown, calcareous, *Tasmanites*	25.0 to 26.5
and, very dark gray-brown, fine to coarse, a few granules and pebbles, heterogeneous composition, subrounded to subangular, very silty, calcareous	30.0 to 31.5
ame	35.0 to 36.5
ill, very dark gray, clayey, calcareous, *Tasmanites*	40.0 to 41.5
ill, very dark gray, very clayey, few sand and pebble grains calcareous, *Tasmanites*	45.0 to 46.5
ame	50.0 to 51.5
ame	55.0 to 56.5
ame	60.0 to 61.5
ame	65.0 to 66.5

DUP 38N9E-6.2b

thern Illinois Toll Road Boring. Drilled 1958 by Soils ing Service. Total depth 61.5 feet. Elevation 732 feet nated from topographic map. Illinois State Geological vey Sample Set 32348. Studied by A. J. Zeizel.

stocene Series	Depth (ft)
ill, yellowish brown, clayey, oxidized, noncalcareous, organic material	1.0 to 2.5
me	3.0 to 4.0
ill, gray, clayey, very few sand grains, oxidized, calcareous, *Tasmanites*	6.0 to 7.5
me	8.5 to 10.0
ll, dark gray, clayey, very few sand grains, calcareous, *Tasmanites*	11.5 to 12.0
me	13.5 to 15.0
nd, yellowish brown, fine to coarse, some granules, subangular to subrounded and silty, clayey, calcareous, *Tasmanites* some gravel, subrounded	16.0 to 17.5
ll, yellowish brown, very sandy and gravelly, calcareous, *Tasmanites*	18.5 to 20.0
me	20.0 to 21.5
ll, very dark gray, sandy, fine to very coarse, not very compact, calcareous	25.0 to 26.5
me	30.0 to 31.5
nd, black and cream, medium to coarse, subangular to subrounded, calcareous	35.0 to 36.5
Till, very dark gray, very clayey, few sand grains, calcareous	40 to 41.5
Same	45.0 to 46.5
Same	50.0 to 51.5
Sand, very pale brown, fine to very coarse, subangular to subrounded, mainly dolomite, very silty, gravel subrounded	55.0 to 56.5
Sand, very pale brown, coarse to very coarse, subangular, almost all dolomite, very silty, gravel, very pale brown, subangular to subrounded, all dolomite	60.0 to 61.5

Well DUP 38N10E-3.2f

Northern Illinois Toll Road Boring. Drilled 1958 by Soils Testing Service. Total depth 35 feet. Elevation 678 feet estimated from topographic map. Illinois State Geological Survey Sample Set 31685. Studied by A. J. Zeizel.

Pleistocene Series	Depth (ft)
Soil, black, clayey, noncalcareous	1 to 2.5
Same	3.5 to 5.0
Till, very dark brown, clayey, oxidized, noncalcareous; sand, light gray to brown, medium to coarse, subangular to subrounded, silty, calcareous, oxidized; gravel, mainly dolomite, subrounded	6.0 to 7.5
Sand, dark yellowish brown, very fine to fine, few granules, subrounded to subangular, very silty, oxidized, calcareous, soil fragments; gravel, mainly dolomite, subangular to subrounded	11 to 12.5
Same	13.5 to 15.0
Same	16.0 to 17.5
Same	18.5 to 20.0
Sand, light yellowish brown, very fine to coarse, some granules, subangular, oxidized, calcareous, soil and wood fragments	25 to 26.5
Clay, some laminated, very dark gray, some pebbles. calcareous, *Tasmanites*; till, very dark gray, clayey, calcareous	30 to 31.5
Dolomite fragments, subangular to angular, few quartz and igneous pebbles, subrounded (wash sample)	(Refusal) 35

Well DUP 38N10E-5.6d

Northern Illinois Toll Road Boring. Drilled 1958 by Soils Testing Service. Total depth 31.5 feet. Elevation 768 feet estimated from topographic map. Illinois State Geological Survey Sample Set 31836. Studied by A. J. Zeizel.

Pleistocene Series	Depth (ft)
Soil, black, silty, noncalcareous	1.5 to 3.0
Till, yellowish brown, clayey, oxidized, calcareous, *Tasmanites*	4.5 to 6.0
Till, yellowish brown, some light gray, clayey, oxidized, calcareous, *Tasmanites*	7.5 to 9.0
Till, yellowish brown to light gray, clayey, oxidized, calcareous, *Tasmanites*	10.5 to 12.0
Same	13.5 to 15.0
Clay till, dark gray, calcareous	16.5 to 18.0
Clay till, dark gray, calcareous, *Tasmanites*	19.5 to 21.0

Clay till, yellowish brown, calcareous, *Tasmanites*	25.0 to 26.5
Clay till, grayish brown, calcareous, *Tasmanites*	30.0 to 31.5

Well DUP 38N10E-12.2b

Belmont High Woods Well No. 2. Drilled 1954 by Layne Western Company. Total depth 295 feet. Elevation 738 feet estimated from topographic map. Illinois State Geological Survey Sample Set 24830. Studied by A. J. Zeizel.

	Depth *(ft)*
Pleistocene Series	
Till, calcareous, yellowish brown, spores	0 to 15
Till, calcareous, dark gray brown, spores	15 to 30
Till, calcareous, brown, spores, shale fragments	30 to 45
Gravel, calcareous, brown, gray subrounded, chiefly dolomite; sand, very coarse, subrounded to rounded.	45 to 80
Gravel, calcareous, gray, brown, subrounded, chiefly dolomite	80 to 85
Gravel, calcareous, gray, brown, subrounded, chiefly dolomite; sand, gray, brown, very coarse, subangular to subrounded	85 to 90
Silurian System	
Niagaran Series	
Dolomite	

Well DUP 38N11E-30.5d

Maple Crest Lake Country Club. Drilled by Red Duck Well Drilling Company. Total depth 395 feet. Elevation 781 feet estimated from topographic map. Illinois State Geological Survey Sample Set 31003. Studied by A. J. Zeizel.

	Thickness *(ft)*	Bottom *(ft)*
No samples		145
Silurian System		
Niagaran Series		
Dolomite, cherty, very pale brown, very fine	5	150
Dolomite, slightly silty, bluish gray, some light gray, brown, very fine, cherty near base	20	170
Dolomite, silty, cherty, greenish gray, very fine	30	200
Dolomite, light gray, very fine, lower 20′ slightly silty	60	260
Dolomite, silty, gray, few black specks, very fine, fine, disseminated pyrite	45	305
''Basal beds''		
Dolomite, slightly silty, pink, yellow, very pale brown to greenish brown, very fine, trace glauconite	15	320
Alexandrian Series		
Dolomite, slightly silty, light brownish gray, few black speckled, very fine, some chert, glauconitic	25	345
Dolomite, cherty, silty, grayish brown, very fine	20	365
Dolomite, very silty, cherty gray brown, very fine; shale, dolomitic, silty, very dark gray	25	390
Ordovician System		
Maquoketa Formation		
Dolomite, very silty, argillaceous, light gray to black, very fine; shale, silty, dolomitic, olive green, weak	5	395

Well DUP 39N9E-3.1h

Campbell Soup Company. Drilled 1947 by Clarence Hugh Total depth 255 feet. Elevation 765 feet estimated fr topographic map. Illinois State Geological Survey Sample 16579. Studied by P. M. Busch, November 1950.

	Depth *(ft)*
Pleistocene Series	
Silt, yellowish orange, some gray, carbonaceous specks	0 to 1
Till, dolomitic, silty, gravelly, yellowish orange to grayish yellow, carbonaceous specks, spores	15 to 2
Gravel to ¼″, clayey, yellowish orange	25 to 3
Gravel to ½″, yellowish gray	35 to 4
Gravel, fine and little sand, silty, little yellowish gray	40 to 7
Till, calcareous, sandy, yellowish gray, carbonaceous specks, spores	75 to 9
Gravel to ⅜″, clayey, yellowish gray	90 to 9
Silurian System	
Dolomite	95 to 2

Well DUP 39N11E-4.1e

Village of Villa Park No. 7. Drilled 1958 by Layne-West Company. Total depth 1420 feet. Elevation 704 feet estima from topographic map. Illinois State Geological Survey Sam Set 30860. Studied by A. J. Zeizel, 0 to 200 feet, 1959; stud by P. R. Stewart, 0 to 1420 feet, 1960.

	Thickness *(ft)*	Bott *(ft*
Pleistocene Series		
Till, slightly silty to sandy, calcareous, very dark gray brown, abundant shale fragments, sporous	15	1
Till, slightly silty to sandy, calcareous, brown, abundant shale fragments, sporous	35	5
Gravel, slightly sandy, silty, calcareous, dark brown to very dark gray, subrounded, black shale, granular, abundant, little till, as above	10	6
Silurian System		
Niagaran Series		
Dolomite, very pure, light gray to gray, light pale brown, very fine to fine; porous to very porous, trace pyrite, trace glauconite, reef?	15	7
Dolomite, slightly silty, slightly argillaceous, white, very fine; porous, crystalline quartz	10	8
Dolomite, slightly silty, slightly argillaceous, light gray, very fine, slightly porous	10	9
Dolomite, cherty, slightly silty, slightly argillaceous, light gray, very fine	15	11
Dolomite, slightly silty, slightly argillaceous, light gray to greenish gray, black speckled very fine, glauconitic	5	11
''Basal beds''		
Dolomite, argillaceous, red, greenish gray, very fine to fine; shale, dolomitic, pink, weak	5	12
Shale, dolomitic, maroon, sandy, weak; dolomite, cherty, greenish gray to maroon, very fine	5	12
Dolomite, argillaceous, greenish, light gray to greenish gray to pink, very fine, slightly porous, thin green shale partings	10	13
Alexandrian Series		
Dolomite, slightly argillaceous, light gray		

to gray, very fine	5	140
Dolomite, slightly silty, slightly argillaceous, light brown gray, very fine, trace glauconite, trace pyrite	20	160
Dolomite, slightly silty, slightly argillaceous, light brown gray to gray, very fine to fine, glauconitic, trace pyrite	15	175
vician System		
ncinnatian Series		
aquoketa Formation		
Shale, silty, dolomitic, maroon, sandy, weak to slightly plastic	5	180
Shale, silty, dolomitic, mottled red, green, yellow, weak to slightly plastic; dolomite, argillaceous, greenish gray, some yellowish gray, very fine	10	190
Shale, silty, calcareous, green, some pink, weak to slightly plastic	10	200

DUP 39N11E-28.6e

rthern Illinois Toll Road Boring. Drilled 1958 by Soils sting Service. Total depth 36.5 feet. Elevation 717 feet imated from topographic map. Illinois State Geological rvey Sample Set 31568. Studied by A. J. Zeizel.

istocene Series	Depth *(ft)*
Till, yellowish brown and dark gray-brown, silty, oxidized, noncalcareous	1.5 to 3.0
Till, yellowish brown, silty, oxidized, calcareous, *Tasmanites*	4.5 to 6.0
Same	7.5 to 9.0
Same	10.5 to 12.0
Soil, black, noncalcareous, wood, *Tasmanites*; till, very dark gray-brown, silty, slightly calcareous	13.5 to 15.0
Till, very dark gray, silty, calcareous	16.5 to 18.0
Till, light reddish brown to greenish gray, silty, calcareous	19.5 to 21.0
Clay, gray, calcareous	25 to 26.5
Sand, medium to coarse, subrounded, subangular; gravel, silty, slightly calcareous	30 to 31.5
Till, dark gray-brown, silty, calcareous, *Tasmanites*	35 to 36.5

DUP 40N9E-33.1a

Ross. Drilled by Chester Diebold. Total depth 150 feet. vation 775 feet. Illinois State Geological Survey Sample 7704. Studied by A. J. Zeizel.

istocene Series	Depth *(ft)*
ill, calcareous, gray	0 to 15
ill, calcareous, yellowish gray	15 to 35
and, coarse, gravelly, shale grains	35 to 55
ravel, up to ¼″	55 to 65
ill, calcareous, yellowish gray	65 to 75
ill, calcareous, light gray	75 to 85
ravel, granular	85 to 95
ravel, up to ½″	95 to 105

DUP 40N11E-13.5b

M. St. P. & P. R.R. No. 6. Drilled 1950 by J. P. Miller esian Well Company. Total depth 1461 feet. Elevation 672 estimated from topographic map. Illinois State Geological vey Sample Set 20203. Studied by T. C. Bushbach, July).

	Thickness *(ft)*	Bottom *(ft)*
Pleistocene Series		
Soil, sandy, silty, brownish black	1	1
Sand and granular gravel, brown	4	5
Till, very silty, calcareous, yellowish orange	7	12
Till, silty, calcareous, grayish brown	48	60
Silurian System		
Niagaran Series		
Dolomite, white to pale green, very fine to medium, partly porous at top; trace of crystalline quartz	45	105
Dolomite, slightly cherty, white to light gray, some pale green, very fine to fine; few *ammodiscus* at base	75	180
Dolomite, slightly silty, white to pale green and light pinkish buff, very fine to fine; *ammodiscus*	20	200
Dolomite, argillaceous, white to pale green, pink, red, fine to medium; *ammodiscus*; *paleoturretelles*	25	225
Alexandrian Series		
Kankakee Formation		
Dolomite, white to light pinkish buff, some greenish, fine	35	260
Ordovician System		
Maquoketa Formation		
Clay, silty, dolomitic, dark red, weak, hematitic, ironstone pebbles; few phosphatic nodules	5	265
Dolomite, argillaceous, silty, light buff, pink, green, fine to medium; bryozoa	15	280
Shale, silty, dolomitic, greenish gray, weak	30	310
Shale, as above; dolomite, argillaceous, silty, greenish gray, fine	40	350
Dolomite, argillaceous, silty, greenish gray to brown, fine to coarse, pyritic	25	375
Dolomite, argillaceous, silty, grayish brown, fine; shale, silty, grayish brown to reddish brown, weak, phosphatic nodules	15	390
Shale, silty, dolomitic, grayish brown, weak; dolomite, argillaceous, greenish gray to grayish brown, fine	10	400
Dolomite, argillaceous, brown to grayish brown, fine to coarse, fossiliferous, pyritic	15	415
Shale, silty, dolomitic, grayish brown, weak; little dolomite, as above	70	485
Galena Formation		
Dolomite, light buff to buff, medium	50	535
Dolomite, light grayish buff to buff, fine to medium; calcareous at base; trace of gush	80	615
Dolomite, light grayish buff to buff, fine to medium, pyritic; vugs filled with clear calcite, some associated with pyrite, coarse calcite crystals at base	45	660
Decorah Formation		
Dolomite, calcareous, gray, buff, red speckled, fine to medium; limestone, light gray, medium	15	675
Platteville Formation		
Limestone, dolomitic, extra fine to fine, light grayish buff; fine dolomite crystals in extra fine limestone matrix; calcite	35	710
Limestone, dolomitic, light gray, sublithographic	5	715

Limestone, very dolomitic, reddish buff to buff, very fine to fine	15	730
Limestone, dolomitic, light buffish gray to gray, sublithographic to lithographic, some coarse fossil	35	765
Dolomite, calcareous, light buffish gray to buff, fine	37	802
Glenwood Formation		
Sandstone, dolomitic, light gray, fine to coarse, compact	5	807
St. Peter Formation		
Sandstone, white, fine to coarse, incoherent, much secondary crystallization	8	815
Sandstone, partly silty, fine to coarse incoherent, secondary crystallization; few pebbles of buff, oolitic chert at base	147	962
Oneota Formation		
Dolomite, white to pinkish buff, fine; chert, white to pale orange, oolitic	3	965
Dolomite, slightly cherty (partly oolitic, partly porous) white to pinkish buff, fine	45	1010
Dolomite, partly sandy, white to pale green, pink, fine; chert, sandy, white, partly oolitic; trace of shale, silty sandy, red, weak	10	1020
Dolomite, white to light pinkish buff, fine; geodic quartz	5	1025
Dolomite, partly sandy, white, pink, red, purple, fine, slightly glauconitic	10	1035
Dolomite, very cherty, partly sandy white to light gray, fine to medium; geodic quartz; trace of shale at base, sandy, red, green, weak	13	1048
Dolomite, cherty, sandy, white to light gray, extra fine; grades to sandstone, dolomitic white, medium; geodic quartz; some shale, silty, red, green, brittle	9	1057
Cambrian System		
Trempealeau Formation		
Dolomite, white to pinkish buff, very fine to medium; geodic quartz at base	63	1120
Dolomite, cherty, partly sandy, white to pink to red, very fine to fine	5	1125
Dolomite, pinkish buff, fine; geodic quartz	45	1170
Dolomite, sandy, reddish buff, fine to medium, slightly glauconitic	10	1180
Franconia Formation		
Dolomite, sandy to very sandy at base, medium, coarsely glauconitic	10	1190
Sandstone, slightly dolomitic, slightly silty, fine, incoherent, very glauconitic	5	1195
Sandstone, very dolomitic, fine to medium, compact, very glauconitic; shale, silty, red, brittle	5	1200
Sandstone, dolomitic, light pinkish buff to light gray, fine to medium, few coarse, friable, glauconitic; shale, silty, red, green, brittle	15	1215
Sandstone, dolomitic, light gray, very fine to fine, incoherent to friable, glauconitic; shale at base, silty, green, brittle	15	1230
Sandstone, as above; dolomite, sandy, silty, greenish gray, fine, glauconitic, pyritic	10	1240
Sandstone, dolomitic, silty, greenish gray, fine, compact, glauconitic	10	1250
Dolomite, sandy, silty, greenish gray, some pinkish, fine, glauconitic, pyritic	15	1265
Ironton-Galesville Formations		
Sandstone, dolomitic (coarse crystalline), white to light pinkish buff, medium to extra coarse, incoherent to compact, rounded; little dolomite, light pinkish buff, fine to coarse	30	1295
Sandstone, slightly dolomitic, white, fine to very coarse, incoherent	25	1320
Sandstone, slightly dolomitic, white, very fine to very coarse, incoherent	10	1330
Sandstone, white, fine to very coarse; some dolomite, pink, red, very fine	5	1335
Sandstone, slightly dolomitic, white, very fine to very coarse, incoherent	25	1360
Sandstone, white, fine to very coarse, incoherent	10	1370
Sandstone, slightly dolomitic, slightly silty, white to light buff, very fine to very coarse, incoherent	35	1405
Sandstone, silty, dolomitic, light pinkish buff, fine to very coarse, incoherent	10	1415
Dolomite, very sandy, pinkish buff, fine; dolomite, sandy, silty, grayish brown, fine	12	1427
Sandstone, dolomitic, slightly silty, white to light buff, very fine to coarse, incoherent	13	1440
Sandstone, dolomitic, gray, fine to coarse, compact, some incoherent	2	1442
Eau Claire Formation		
Shale, sandy, silty, dolomitic, greenish gray, brittle	3	1445
Dolomite, very argillaceous, sandy, silty, brown, very fine to fine	5	1450
Shale, silty, dolomitic, greenish gray, weak	5	1455
Dolomite, argillaceous, sandy, silty, greenish gray to brown, fine, glauconitic, pyritic	6	1461

APPENDIX C

SPECIFIC CAPACITY DATA FOR WELLS IN SILURIAN DOLOMITE AQUIFER

Owner	Depth (*ft*)	Penetration (*ft*)	Date of test	Length of test (*hr*)	Nonpumping level (*ft*)	Pumping rate (*gpm*)	Drawdown (*ft*)	Specific capacity (*gpm/ft*)		Specific capacity per foot of penetration (*gpm/ft*^{2})		Stratigraphic units penetrated*	Estimated coefficient of transmissibility (*gpd/ft*)	Remarks
								actual	adjusted	actual	adjusted			
Argonne Nat'l Lab.	341	226	1949	....	82	550	32	17.2	26.1	0.08	0.12	$N_{115}A_{70}M_{41}$	48,000	Well No. 4
Argonne Nat'l Lab.	345	235	1948	....	105	200	3	66.7	80.0	0.28	0.34	$N_{150}A_{75}M_{10}$	160,000	Well No. 5
Argonne Nat'l Lab.	155	40	1949	....	107	43	2	21.5	22.6	0.54	0.56	N_{40}	41,000	Meteorological Bldg.
Argonne Nat'l Lab.	284	219	1948	....	24	200	17	11.8	13.6	0.05	0.06	$N_{135}A_{70}M_{14}$	24,000	Well No. 1
Argonne Nat'l Lab.	300	239	1948	....	21	750	86	8.7	16.9	0.03	0.06	$N_{120}A_{123}M_{27}$	30,000	Well No. 2
Elmhurst-Chicago Stone Co.	266	198	1957	8	10	1270	86	14.8	110.0	0.07	0.55	$N_{40}A_{60}M_{101}$	225,000	Well No. 1
City of Naperville	178	134	1943	8	11	620	11.5	53.8	105.0	0.40	0.78	$N_{21}A_{95}M_{18}$	209,000	Well No. 4
Reber Preserving Co.	200	......	....	3	48	100	14	7.2	6.9	......	......		11,000	
Lawn Meadow Subdiv.	210	188	1956	4	11	200	63	3.2	3.5	0.02	0.02	$N_{15}A_{55}M_{125}$	5,000	Well No. 1
Ill. Toll Hwy Comm.	420	318	1958	....	58	100	1	100.0	111.0	0.32	0.35	$N_{118}A_{50}M_{150}$	226,000	M-8
Village of Lisle	233	148	1959	2.5	68	726	10	72.6	180.0	0.49	1.22	$N_{108}A_{39}M_{1}$	384,000	Village Well No. 2
Schieser School	170	55	1955	....	123	200	6	33.3	286.0	0.61	5.19	N_{55}	610,000	Well No. 1
Oakview Subdiv.	200	85	1957	6.5	96	305	12	25.4	35.0	0.30	0.41	N_{85}	64,000	
Schaffer Bearing Div.	250	196	1955	22	50	620	2	310.0	887.0	1.58	4.52	$N_{135}A_{61}$	2,400,000	
Downers Grove Sanitary Dist.	150	75	....	24	33	75	1	75.0	97.0	1.00	1.29	N_{75}	192,000	
Village of Belmont	295	205	1954	3	84	340	4	85.0	118.0	0.41	0.58	$N_{150}A_{50}M_{5}$	235,000	Village Well No. 2
Maple Hill Improv. Assoc.	158	64	1958	.5	94	150	8	18.7	19.0	0.29	0.30	N_{64}	35,000	Well No. 2
Benedict Sisters Sacred Heart	300	200	....	8.7	65	35	19	1.8	2.1	0.09	0.01	$N_{85}A_{30}M_{85}$	4,000	
Benedict Sisters Sacred Heart	237	142	1939	....	57	140	65	2.2	2.3	0.02	0.02	$N_{90}A_{30}M_{22}$	4,000	
St. Procopius College	245	155	1935	....	62	200	8.5	23.6	27.4	0.15	0.18	$N_{60}A_{75}M_{20}$	51,000	
City of Naperville	190	159	1947	....	12	560	41	13.7	23.7	0.09	0.15	$N_{90}A_{69}$	43,000	City Well No. 5
City of Naperville	202	172	1948	....	10	400	25	16.0	22.2	0.09	0.13	$N_{90}A_{65}M_{17}$	41,000	City Well No. 6
Woodridge Subdiv.	334	237	1959	....	89	530	1	530.0	589.0	2.22	2.48	$N_{138}A_{95}M_{4}$	1,300,000	Well No. 1
Surety Builders	......	......	1958	8	77	60	2.5	24.0	29.4	......	......		55,000	
Village of Hinsdale	271	226	1947	3.5	58	970	76	12.8	33.3	0.06	0.15	$N_{178}A_{35}M_{13}$	61,000	Village Well No. 2
Village of Hinsdale	210	165	1947	5	61	700	80	8.7	16.1	0.05	0.10	N_{165}	25,000	Village Well No. 3
Village of Hinsdale	209	179	1924	....	17	520	3	173.2	347.0	0.97	1.94	N_{179}	750,000	Village Well No. 1
Hinsdale Golf Club	165	20	1944	4.5	90	525	23	22.8	36.0	1.14	1.80	N_{20}	64,000	
Village of Downers Grove	300	210	1958	5	109	850	76	11.2	22.3	0.05	0.11	$N_{165}A_{45}$	40,000	Village Well No. 9
Village of Downers Grove	250	183	1947	1	46	860	12	71.5	218.0	0.39	1.19	N_{183}	500,000	Village "Lee" Well
Village of Downers Grove	295	195	1945	10	96	980	15	65.4	340.0	0.34	1.74	$N_{145}A_{50}$	740,000	Village "Park" Well
Village of Downers Grove	262	197	1953	....	64	412	5	82.4	129.0	0.42	0.66	$N_{145}A_{50}M_{2}$	267,000	Village Well No. 8
Village of Westmont	313	190	1938	11	101	600	1.2	500.0	2000.0	2.63	12.13	$N_{120}A_{68}M_{5}$	5,000,000	Village Well No. 2
Village of Clarendon Hills	250	210	1932	....	95	150	11.5	13.0	14.6	0.06	0.07	N_{210}	26,000	Village Well No. 2
Village of Clarendon Hills	......	......	1947	2	113	300	4	75.0	93.8	......	......		193,000	Village Well No. 2
Blackhawk Subdiv.	295	205	1953	8	102	210	24	8.7	10.4	0.04	0.05	$N_{115}A_{80}M_{10}$	17,000	Well No. 1
Village of Westmont	302	167	1947	24	123	250	20	12.5	15.8	0.08	0.09	$N_{135}A_{32}$	28,000	Village Well No. 3
Village of Westmont	313	208	1958	12	128	259	27	9.6	12.1	0.06	0.06	$N_{120}A_{75}M_{10}$	21,000	Village Well No. 4
Village of Clarendon Hills	354	239	1945	....	91	385	12	32.1	45.9	0.13	0.19	$N_{150}A_{80}$	87,000	Village Well No. 3
Village of Clarendon Hills	370	255	1956	3	90	838	8	105.0	440.0	0.41	1.72	$N_{130}A_{122}M_{3}$	1,000,000	Village Well No. 4
Village of Hinsdale	319	230	1954	....	69	708	10	70.8	173.0	0.31	0.75	$N_{106}A_{34}$	366,000	Village Well No. 5
Village of Hinsdale	212	119	1954	....	73	360	12	30.0	41.0	0.25	0.34		78,000	Test Well
Village of Hinsdale	291	198	1954	....	73	388	7	55.5	80.8	0.28	0.41	$N_{112}A_{56}$	160,000	Test Well
Hinsdale San. Dist.	200	182	1957	....	22	150	126	1.2	1.3	0.01	0.01		2,000	Test Well
Ill. Toll Hwy Comm.	238	138	1957	....	25	157	55	2.9	3.1	0.02	0.02		5,000	Well No. 1
International Harvester Co.	294	239	1956	4	78	400	20	20.0	25.2	0.08	0.11	$N_{175}A_{50}M_{14}$	38,000	Well No. 1
International Harvester Co.	398	296	1957	....	70	500	10	50.0	84.8	0.17	0.29	$N_{173}A_{60}M_{63}$	170,000	Well No. 2
International Harvester Co.	294	199	1957	8	73	580	10	58.0	108.0	0.29	0.54	$N_{175}A_{24}$	222,000	Well No. 3
Brookhaven Manor	317	218	1960	3	115	100	90	1.1	1.1	0.05	0.01	$N_{151}A_{55}M_{12}$	2,000	Well No. 2
Maple Crest Lake Country Club	395	250	1958	8	134	320	22	14.5	19.5	0.06	0.06	$N_{175}A_{170}M_{5}$	34,000	
Cass School Dist. 63	250	155	1958	8	90	147	10	14.7	17.3	0.10	0.11	$N_{140}A_{15}$	32,000	Well No. 1
Campbell Soup Co.	250	155	1946	....	64	282	5	56.4	70.7	0.36	0.46		140,000	Well No. 1
Campbell Soup Co.	255	160	1947	....	45	180	15.0	12.0	13.6	0.08	0.09	$N_{30}A_{87}M_{43}$	24,000	Well No. 2
Campbell Soup Co.	248	154	1958	4	68	75	78	1.0	1.0	0.01	0.01	$N_{31}A_{87}M_{36}$	2,000	Well No. 4
City of W. Chicago	310	228	1950	....	73	510	41	12.4	18.9	0.05	0.08	$N_{50}A_{72}M_{100}$	34,000	Well No. 3
City of W. Chicago	322	233	1947	....	82	500	18	27.8	44.6	0.12	0.19	$N_{60}A_{75}M_{98}$	85,000	Well No. 2
Western Electric Co.	265	200	1958	....	87	215	3.5	61.3	154.0	0.30	0.77	$N_{27}A_{70}M_{103}$	320,000	Well No. 3
Western Electric Co.	257	193	1958	2.5	77	196	19	10.3	11.6	0.05	0.06	$N_{27}A_{70}M_{96}$	20,000	Well No. 2
Western Electric Co.	268	204	1958	10	78	542	40	13.5	22.9	0.07	0.11	$N_{30}A_{75}M_{98}$	42,000	Well No. 1
Lindsay Chemical Co.	332	243	1953	....	72	800	38	21.1	50.6	0.09	0.22	$N_{40}A_{00}M_{112}$	98,000	Well No. 2
Northwestern Chemical Co.	320	245	1957	....	95	150	11	13.6	15.1	0.06	0.06	$N_{60}A_{75}M_{10}$	27,000	Well No. 1
Molded Products Corp.	330	237	1953	....	86	465	32	14.5	21.3	0.06	0.09	$N_{27}A_{110}M_{100}$	39,000	Well No. 1
Winfield Sanitorium	200	75	1939	3	46	60	9	6.7	6.9	0.09	0.09	$N_{47}A_{28}$	10,000	
Village of Winfield	335	205	1958	8	85	400	5	80	122.0	0.39	0.60	$N_{68}A_{45}M_{92}$	245,000	Village Well No. 2
Village of Winfield	254	124	1957	....	75	234	63	3.7	4.3	0.03	0.03	$N_{68}A_{45}M_{11}$	7,000	Village Well No. 2
Elmhurst-Chicago Stone Co.	273	218	1957	....	17	570	16	35.6	64.8	0.16	0.30	$N_{50}A_{60}M_{108}$	128,000	Well No. 2

Well number	Owner	Depth (*ft*)	Penetration (*ft*)	Date of test	Length of test (*hr*)	Nonpumping level (*ft*)	Pumping rate (*gpm*)	Drawdown (*ft*)	Specific capacity (*gpm/ft*)		Specific capacity per foot of penetration (*gpm/ft*^{2})		Stratigraphic units penetrated*	Estimated coefficient of transmissibility (*gpd/ft*)	Re
									actual	adjusted	actual	adjusted			
DUP—															
39N10E-2.3e	Ray Spaulding School	160	77	1958	....	22	100	1	100.0	111.1	1.30	1.34	$N_{40}A_{16}M_{18}$	228,000	Well No.
39N10E-9.2f	City of Wheaton	341	246	1954	....	45	863	79	10.9	26.2	0.04	0.11	$N_{82}A_{55}M_{105}$	49,000	City We
39N10E-10.3b	Jefferson Ice Co.	134	19	1944	....	65	80	5	16.0	17.0	0.85	0.90	N_{19}	31,000	
39N10E-10.4c	Rathkum Farm Prod. Co.	138	18	1944	5	40	70	5	14.0	15.3	0.78	0.85	N_{18}	29,000	
39N10E-11.7c1	Village of Glen Ellyn	310	195	1916	....	42	500	93	5.4	7.7	0.03	0.04	$N_{50}A_{40}M_{105}$	13,000	
39N10E-11.7c2	Village of Glen Ellyn	352	236	1947	6.5	76	750	68	11.0	21.7	0.05	0.09	$N_{49}A_{40}M_{145}$	38,000	Village
39N10E-11.8c	Village of Glen Ellyn	422	290	1947	6	98	750	72	10.4	19.0	0.04	0.07	$N_{83}A_{65}M_{142}$	35,000	Village
39N10E-12.4a	Glen Oak Country Club	202	152	....	....	2	150	11	13.6	15.2	0.09	0.10	$N_{80}A_{68}M_{4}$	27,000	Well No
39N10E-12.4c	Glen Oak Country Club	212	132	1958	6	24	450	50	9.0	13.3	0.07	0.10	$N_{75}A_{50}M_{12}$	21,000	Well No.
39N10E-15.1b	Village of Glen Ellyn	422	262	1954	....	85	765	19	40.3	99.3	0.15	0.38	$N_{90}A_{40}M_{132}$	200,000	Village
39N10E-16	Hitchcock Publishing Co.	200	87	1957	....	60	32	1	32.0	32.0	0.37	0.37		50,000	Well No.
39N10E-16.6c	City of Wheaton	330	64	1946	1	45	320	4	80.0	93.0	1.25	0.37	$N_{105}A_{70}M_{75}$	195,000	City We
39N10E-18.6e	DuPage Co. Hwy Dept.	265	180	1958	8	25	156	5	31.2	37.0	0.17	0.21	$N_{65}A_{80}M_{35}$	70,000	Well No.
39N10E-19.4h	St. Francis Academy	252	170	1957	5	38	260	2	130.0	180.0	0.76	1.06	$N_{80}A_{80}M_{12}$	375,000	
39N10E-30.1h	Arrowhead Subdiv.	335	250	1947	8	40	759	13	58.3	159.0	0.23	0.68	$N_{80}A_{50}M_{105}$	328,000	
39N10E-34.3d	Morton Arboretum	250	177	1956	4	75	690	2	345.0	1115.0	1.95	6.38	$N_{135}A_{40}$	2,650,000	Well No.
39N10E-34.4d	Morton Arboretum	250	175	1956	24	85	720	6	120.0	403.0	0.69	2.30	$N_{135}A_{40}$	910,000	Well No.
39N10E-35.5g	Valley View Subdiv.	250	200	1957	12	32	560	7.5	74.6	150.0	0.37	0.75	$N_{140}A_{55}M_{5}$	310,000	Well No.
39N10E-35.6g	Valley View Subdiv.	290	179	1957	5	80	536	11	48.8	86.0	0.27	0.49	$N_{82}A_{65}M_{30}$	165,000	Well No.
39N11E-1		301	......	....	....	27	152	2	76.0	89.4	......	......		180,000	
39N11E-1	J. F. Kyle	237	183	1955	5.5	61	190	27	7.0	8.5	0.04	0.05		15,000	
39N11E-3.2e	Black Top Road Co.	195	159	1956	6	37	240	8	30.0	37.5	0.19	0.24	N_{159}	69,000	
39N11E-3.3a	Robert Hall Clothes	114	26	1958	2	38	200	2	100.0	131.0	3.86	5.04		260,000	Well No.
39N11E-4.1e	Village of Villa Park	235	170	1944	....	33	220	3	73.4	91.8	0.43	0.54	$N_{120}A_{40}M_{10}$	185,000	Village
39N11E-5.3g	Lombard Heights	209	124	1954	10	43	335	17	19.7	25.7	0.16	0.21	$N_{70}A_{50}M_{5}$	47,000	Well No.
39N11E-7.1h1	Village of Lombard	175	115	1948	....	9	365	27	13.5	21.3	0.12	0.19	$N_{70}A_{38}M_{7}$	39,000	Village
39N11E-7.1h2	Village of Lombard	175	103	1948	....	9	80	1.0	80.0	114.0	0.78	1.10	$N_{58}A_{40}M_{5}$	232,000	Test We
39N11E-8.7h	Village of Lombard	84	14	1939	....	10	465	21	22.1	33.7	1.58	2.41	N_{14}	63,000	Village
39N11E-10	Wander Co.	220	......	1922	....	19	350	40	8.8	11.3	......	......		20,000	Well No.
39N11E-10	Wander Co.	187	......	1924	....	26	500	55	9.1	13.5	......	......		24,000	Well No.
39N11E-10.8e	Village of Villa Park	285	227	1955	....	57	500	70	7.1	10.5	0.03	0.05	$N_{92}A_{35}M_{100}$	18,000	Village
39N11E-10.8d	Village of Villa Park	251	193	1955	....	57	500	4	125.0	238.0	0.65	1.23	$N_{92}A_{35}M_{66}$	558,000	Village
39N11E-10.8d	Village of Villa Park	187	129	1924	4.5	26	500	55	9.1	13.2	0.07	0.10	$N_{92}A_{35}M_{2}$	22,000	Village
39N11E-13.3g	City of Elmhurst	290	210	1959	8	74	335	86	3.9	5.1	0.01	0.02	$N_{130}A_{50}M_{30}$	8,000	City We
39N11E-16	City of Wheaton	175	......	1960	....	38	830	31	27.0	71.6	......	......		122,000	City We
39N11E-20.1g	West York Center Subdiv.	235	140	1947	....	66	195	55	3.5	6.9	0.03	0.05	$N_{120}A_{20}$	11,000	
39N11E-20.6g	Highland Hills Subdiv.	241	135	1954	....	29	483	114	4.2	5.9	0.03	0.04	$N_{87}A_{37}M_{11}$	10,000	Well No.
39N11E-23.1a	Ill. Toll Hwy Comm.	290	227	1958	....	26	60	1	60.0	66.6	0.26	0.29	$N_{127}A_{95}M_{5}$	132,000	EP-3
39N11E-24.2g	J. Harris Jones	350	290	1959	....	45	350	65	5.4	6.9	0.02	0.02	$N_{140}A_{48}M_{102}$	12,000	
39N11E-34	Liberty Park Home Owners Assoc.	279	179	1956	....	103	136	53	2.6	2.8	0.01	0.02		4,000	
39N11E-34.2g	St. Francis Retreat	298	161	1950	8	55	180	134	1.3	1.6	0.01	0.01	$N_{98}A_{40}M_{23}$	3,000	
39N11E-34.5e	St. Joseph College	250	135	1958	....	84	60	15	4.0	8.6	0.03	0.06	$N_{130}A_{5}$	15,000	Well No.
39N11E-36	Camp Fullersburg	120	30	1933	....	14.5	30	.5	60.0	60.0	2.00	2.00		118,000	
40N9E-28.4b1	Christ the King Seminary	340	228	1954	24	82	254	85	3.0	3.7	0.01	0.02	$N_{18}A_{70}M_{140}$	6,000	Well No.
40N9E-28.4b2	Christ the King Seminary	160	55	1957	8	54	100	30	3.3	3.6	0.06	0.07	$N_{33}A_{22}$	6,000	Well No.
40N9E-32.5g1	Kawneer Corp.	271	203	1955	....	50	421	60	7.0	9.5	0.03	0.05	$N_{42}A_{70}M_{91}$	16,000	Well No.
40N9E-34.3g	De Vito Co.	140	43	1958	2	29	24	3	8.0	8.6	0.18	0.20	$N_{30}A_{13}$	14,000	Well No.
40N9E-35.3g	Sidwell Studios	192	82	1958	....	28	81	63	1.3	1.4	0.01	0.02	$N_{20}A_{55}M_{10}$	2,000	Well No.
40N10E-3.4e1	Village of Roselle	182	43	1926	6.5	37	110	14	7.9	8.8	0.18	0.20	$N_{16}A_{25}M_{2}$	15,000	Village
40N10E-3.4e2	Village of Roselle	183	43	1953	3	47	142	10	14.2	15.2	0.33	0.35	$N_{15}A_{25}M_{3}$	27,000	Village
40N10E-12.7b	Medinah Country Club	145	85	1945	....	11	250	17	14.7	17.7	0.17	0.21	N_{85}	32,000	
40N10E-20.5d	Allied Cement Co.	320	200	1958	5	60	85	16	5.3	5.6	0.03	0.03	$A_{35}M_{160}$	9,000	Well No.
40N10E-26.5d	North Glen Ellyn Utilities	353	232	1959	10	50	300	129	2.3	2.8	0.01	0.01	$N_{24}A_{25}M_{173}$	4,000	
40N10E-31.2g	Carol Stream Utilities Co.	335	225	1958	1.5	40	408	9	45.3	122.0	0.20	0.54	$N_{70}A_{55}M_{100}$	260,000	
40N11E-8.4f	Village of Itasca	200	129	1959	8	7	115	40	2.9	3.4	0.02	0.03	N_{129}	5,000	Test W
40N11E-8.6c	Village of Itasca	190	108	1958	5.5	28	70	122	0.6	0.6	0.01	0.01	N_{108}	1,000	Village
40N11E-8.6f	Village of Itasca	200	120	1947	1	2	350	20	17.5	20.5	0.15	0.17	N_{120}	37,000	Village
40N11E-8.8f	Village of Itasca	185	102	1947	2	62	50	108	0.5	0.5	0.01	0.01	N_{102}	1,000	Village
40N11E-24.4b	River Forest Golf Club	219	164	1959	1	28	200	44	4.5	4.5	0.03	0.03	$N_{120}A_{41}M_{3}$	7,000	
40N11E-28.3a	Village of Addison	221	150	1957	....	14	600	109	5.5	8.7	0.04	0.06	$N_{74}A_{45}M_{31}$	15,000	Village
40N11E-28.3f	Village of Addison	91	21	1950	2	....	98	7	14.0	15.2	0.67	0.72	N_{21}	27,000	Village
40N11E-28.4f	Village of Addison	155	65	1925	10	18	150	2	75.0	90.5	1.15	1.39	N_{65}	175,000	Village
40N11E-28.7b	Village of Addison	152	66	1934	6	20	200	10	20.0	24.0	0.30	0.36	N_{66}	43,000	
40N11E-33.7f	Village of Addison	250	176	1959	....	30	453	85	5.3	7.3	0.03	0.04	$N_{111}A_{65}$	12,000	Village

* N = Niagaran Series; A = Alexandrian Series; M = Maquoketa Formation. Subscript number indicates depth of penetration in unit, in feet.

APPENDIX D

WATER-LEVEL DATA FOR WELLS IN THE SILURIAN DOLOMITE AQUIFER

Well number	Owner	Depth of well *(ft)*	Casing diameter *(in)*	Surface elevation *(ft above sea level)*	Depth to water *(ft)*	Water level elevation *(ft above sea level)*	Date of measurement 1960	Remarks
P—								
11E-3.7b	Argonne Nat'l Lab.	104	6	690	52.61	637	6-2	Well No. 17
11E-4.8d	Argonne Nat'l Lab.	162	4	752	107.28	645	6-2	Well No. 31
11E-8.1c	Argonne Nat'l Lab.	152	4	748	106.95	641	6-2	Well No. 30
11E-8.2h	Argonne Nat'l Lab.	345	12	751	105.74	645	6-2	Well No. 5
11E-9.2c	Argonne Nat'l Lab.	130	6	712	79.54	632	6-2	Well No. 24
11E-9.3e	Argonne Nat'l Lab.	183	4	714	88.55	625	6-2	Well No. 35
11E-9.4c	Argonne Nat'l Lab.	116	4	745	109.97	635	6-2	Well No. 13
11E-9.8c	Argonne Nat'l Lab.	111	4	733	92.98	640	4-1	Well No. 9
11E-10.2f	Argonne Nat'l Lab.	79	4	686	59.87	626	6-2	Well No. 26
11E-10.6b	Argonne Nat'l Lab.	95	4	663	67.64	595	6-3	Well No. 8
11E-10.6f	Argonne Nat'l Lab.	95	4	670	40.50	630	6-2	Well No. 6
11E-10.8e	Argonne Nat'l Lab.	202	6	708	77.50	631	6-2	Well No. 36
11E-10.8f	Argonne Nat'l Lab.	150		690	52.10	638	6-2	Well No. 34
11E-11.7d	Argonne Nat'l Lab.	185	4	715	123.65	591	6-2	Well No. 18
11E-17.3e	Argonne Nat'l Lab.	150	6	722	124.40	598	6-2	Well No. 25
11E-17.4d	Argonne Nat'l Lab.	127	4	690	84.44	606	6-2	Well No. 32
9E-1.5g	G. O. Hoelle	225	6	750	66.47	684	6-28	
9E-2.1h	Elmhurst-Chicago Stone Co.	265	16	690	8.60	681	6-28	Well No. 1
9E-2.7h	W. Stokes	103	5	696	6.24	690	6-28	
9E-3.1e	F. Engel		4	700	17.01	683	6-29	
9E-4.2h	R. Watts	90	4.5	720	20.48	700	6-20	
9E-6.7f	R. Benke	96	6	730	24.90	705	6-30	
9E-7.4g	W. Dicke	100	6	730	30.83	699	6-30	
9E-8.8d	A. M. Harris	180	6	740	37.08	703	6-22	
9E-9.2e	Westview Utilities	205	12	707	25.00	682	9-28	Scots Plains Subdiv., Well No. 1
9E-9.7h	Laura Mattes	160	6	715	31.86	683	6-22	
9E-13.5e	C. Manes	60	4	700	16.77	683	6-20	
9E-14.2g	Kahn	67	5	688	12.28	676	6-20	
9E-14.3h	Ehrhart	38	5	690	9.34	681	6-20	
9E-16.1h	Crosier School	103	5	705	18.22	687	6-20	
9E-17.8c2	Warren Petroleum Co.	282	8	712	24.0	688	6-22	Well No. 2
9E-17.8d	Reber Preserving Co.	200	8	712	25.5	687	6-22	Well No. 2
9E-23.3g	Lawn Meadow Water Co.	210	10	695	5.5	690	7-1	Well No. 1
9E-24.8b	Hartmeyer		5	706	13.75	692	6-23	
9E-27.1c	K. Davis	175	5	702	12.91	689	8-18	
9E-28.1d	L. Brummel	225	7	710	18.76	691	8-18	
9E-29.7b2	P. Hinz	130	4.5	712	41.22	671	8-18	
9E-30.2a	E. Frieders	142	4	710	37.70	672	8-18	
9E-35.3e	E. Sucher		5	677	19.76	657	8-18	
9E-36.8g	Peterold		5	673	19.82	653	8-18	
0E-1.1g	Univ. of Ill. Experiment Station	250	6	720	55.0	665	8-18	
0E-2.3d	E. Donda	117	6	732	78.93	653	8-19	
0E-3.8a	Ill. Municipal Water Co.	233	12	723	67.0	658	8-18	Village of Lisle, Well No. 2
0E-4.5g	W. H. Geolitz		5	745	36.00	709	8-18	
0E-5.4e	Ill. Toll Hwy. Comm.	420	12	760	57.0	703	7-8	Well M-8
0E-5.6f	A. L. Tholin	165	5	765	64.5	701	7-8	
0E-10.2g1	Ill. Municipal Water Co.	231		671	43.0	628	6-1-59	Village of Lisle, Well No. 1
0E-10.7a1	Sacred Heart Academy	53	4	670	11.0	659	10-19	Well No. 1
0E-10.7a2	Sacred Heart Academy	152	6	670	16.30	654	6-21	Farm Well No. 2
0E-11.7c	DuPage Utilities Co.	200	8	740	91.0	649	6-16	Oakview Subdiv., Well No. 1
0E-12.2b	Belmont-Highwood Water District	295	10	740	92.0	648	7-8	Well No. 2
0E-12.2d	Belmont-Highwood Water District	148	5	698	43.0	655	7-8	Well No. 1

Well number	Owner	Depth of well *(ft)*	Casing diameter *(in)*	Surface elevation *(ft above sea level)*	Depth to water *(ft)*	Water level elevation *(ft above sea level)*	Date of measurement 1960	Remarks
DUP—								
38N10E-12.5c	Shaefer Bearing Div.	250	12	710	49.85	660	7-8	
38N10E-12.6g2	Northwest Belmont Improvement Assoc.	167	6	750	79.39	671	7-8	Well No. 2
38N10E-12.7f	Downers Grove Sanitary District	150	6	698	39.0	659	7-8	
38N10E-13.1g	E. Dunning	156	4	750	105.61	644	10-7	
38N10E-13.8e	J. E. Wurl	120	6	750	102.09	648	10-3	
38N10E-14.8c1	M. Draus	80	6	680	26.31	654	11-11	
38N10E-14.8h	G. Lawford	75	6	710	59.88	650	10-3	
38N10E-15.3g	F. China	70	5	655	5.73	647	10-3	
38N10E-17.6d	Naperville Country Club	120	6	752	65.49	687	12-5	
38N10E-18.3d1	City of Naperville	189	30	695	9.0	686	6-13	City Well No. 5
38N10E-19.4e	H. Hoyle	105	4	712	50.02	662	6-29	
38N10E-20.4h	Marie Marquarot	180	6	743	63.23	680	10-14	Tenant
38N10E-21.1e	Fred Wardle	185	4	752	98.31	654	11-3	
38N10E-22.1h	Woodridge Golf Club	136	14	662	17.00	645	11-3	
38N10E-22.2a	Everett A. Brown	59	6	675	30.57	644	10-17	
38N10E-22.3g	Woodridge Golf Club	164	10	656	8.00	648	11-3	
38N10E-22.6a	E. O. Pionke	90	4	702	53.45	649	11-3	
38N10E-23.1a	C. F. Nadehhoffer	109	4	730	81.40	649	6-21	
38N10E-23.2f	H. C. Vial	180	5	730	83.80	646	6-21	
38N10E-23.3d	H. C. Vial	120	5	750	104.78	645	6-21	
38N10E-23.6c	Goodrich School	160	6	720	64.70	655	12-1	
38N10E-24.1g	John Posluany, Jr.	185	6	721	77.84	643	12-12	
38N10E-24.8g1	Unknown	120	4	720	72.49	648	4-4	
38N10E-25.1c	R. H. Scudder	182	6	783	139.95	643	12-2	
38N10E-26.5c	George A. Karl	175	6	714	64.24	650	12-1	
38N10E-27.3d	Everett A. Brown	57	6	665	25.45	640	10-17	
38N10E-27.6h	E. D. Pionke	114		695	46.26	649	10-18	
38N10E-28.6h	George Huddlestone	180	4	760	92.63	667	10-14	
38N10E-31.2b	J. Fender	65	4	653	20.39	633	8-18	
38N10E-33.6a	A. Lissen	121	6	725	65.98	659	6-21	
38N10E-34.8c	Richard Nielson	170	5	716	70.43	646	10-18	
38N10E-35.2d	H. Maas	123	4	745	101.97	643	6-21	
38N10E-35.5h	Adam Kohley	60	4	682	32.05	650	10-17	
38N10E-35.6a	Dean E. McMillan	120	3	675	36.27	639	12-1	
38N10E-36.5b	J. E. Subat	180	6	763	125.07	638	11-28	
38N11E-1.3a1	Village of Hinsdale	273	20	686	67	619	6-9	Village Well No. 2
38N11E-1.3a2	Village of Hinsdale	210		687	77	610	6-9	Village Well No. 3
38N11E-1.4a	Village of Hinsdale	209	12	676	53	623	6-9	Village Well No. 1
38N11E-4.3f2	Liberty Park Home Owners Assoc.	278	8	745	99	646	6-13	Well No. 1
38N11E-6.5c	Village of Downers Grove	300	30	757	105	652	6-13	Village Well No. 9
38N11E-7.6d	Village of Downers Grove	250	30	696	80	616	6-4	Village Well No. 6
38N11E-8.4b	Village of Downers Grove	291	30	742	98.5	643	5-31	Village Well No. 7
38N11E-8.7e	Village of Downers Grove	262	30	720	70	650	6-13	Village Well No. 8
38N11E-9.1h	Village of Westmont	313	16	752	101	651	6-14	Village Well No. 2
38N11E-10.1e	Village of Clarendon Hills	250	12	723	112	611	6-10	Village Well No. 2
38N11E-10.6e	Ill. Municipal Water Co.	295	12	740	116	624	7-11	Blackhawk Heights Subdiv., Well No
38N11E-10.7a	Village of Westmont	302	17	760	132	628	7-11	Village Well No. 3
38N11E-10.8e	Village of Westmont	313	12	755	128	627	6-14	Village Well No. 4
38N11E-11.5b	Village of Clarendon Hills	354	12	737	104.0	633	6-10	Village Well No. 3
38N11E-11.5d	Village of Clarendon Hills	370	12	710	89.0	621	6-10	Village Well No. 4
38N11E-20.6c	C. V. Baxter	130	4	760	115.63	644	9-30	
38N11E-20.7c	H. A. Pfaff	213	5	763	117.97	645	9-29	
38N11E-20.7e	C. L. Bain	167	4	760	114.35	646	4-18	
38N11E-21.1c	Clarendon Hills Cemetery	249	6	764	127.60	636	4-18	
38N11E-24.4b	International Harvester Co.	398	16	718	102	616	7-11	Well No. 1
38N11E-24.4c	International Harvester Co.	294	16	715	85	630	7-11	Well No. 2
38N11E-27.8d	Brookhaven Manor Water Co.	310	16	755	113.55	641	6-14	Well No. 1
38N11E-28.1c	Brookhaven Manor Water Co.	330	16	760	114.0	646	6-14	Well No. 2
38N11E-30.1a	F. Coffee	165	4	770	124.78	645	4-1	
39N9E-1.2b	F. Muser	120	3	735	22.10	713	7-5	
39N9E-3.1h2	Campbell Soup Co.	248	8	763	57.92	705	7-6	Well No. 4

Well number	Owner	Depth of well (ft)	Casing diameter (in)	Surface elevation (ft above sea level)	Depth to water (ft)	Water level elevation (ft above sea level)	Date of measurement 1960	Remarks
P—								
9E-3.8g	H. Raffel	161	5	792	75.64	716	7-6	
9E-4.1b	City of West Chicago	310	24	762	87.0	675	8-3	Well No. 3
9E-4.7g	L. C. Carbary	108	6	760	39.95	720	7-6	
9E-5.1h	R. Burns		4	753	28.74	724	7-6	
9E-5.5g1	Western Electric Co.	257	8	752	92.0	660	8-7	Well No. 2
9E-5.5g2	Western Electric Co.	265	8	752	92.0	660	8-7	Well No. 1
9E-5.6g	Western Electric Co.	268	8	752	86.0	666	8-7	Well No. 3
9E-6-1e2	W. H. Poppino	115	4	750	44.93	705	7-5	
9E-7.2h	I. McMahon	107	5	750	54.59	695	7-5	
9E-9.6e	General Mills, Inc.	330	12	758	68	690	7-5	Well No. 1
9E-10.3d	F. Glashagle	150	5	760	44.85	715	7-5	
9E-11.2h	B. Spiers	115	5	742	31.74	710	7-5	
9E-11.5b	G. Peters	98	5	725	30.79	694	7-5	
9E-12.4b	Winfield Hospital	200	8	762	53.5	709	6-29	Well No. 2
9E-13.2h1	Village of Winfield	263	8	768	59.7	708	6-14	Village Well No. 3
9E-13.6b	Village of Winfield	335	12	778	81.0	697	6-14	Village Well No. 2
9E-14.5b	Mack		4.5	772	60.94	711	6-29	
9E-16.2e	C. Claypool		5	720	27.84	692	6-29	
9E-17.8c	A. Schuslar		3	740	20.04	720	6-29	
9E-18.1h	McChesney	127	3.5	746	35.75	710	6-29	
9E-23.3a	E. J. Davidson	143	6	730	23.00	707	6-28	
9E-24.7g	C. Pomillo		5	771	63.41	708	6-28	
9E-25.3d	J. Gorak		5	756	44.59	711	6-28	
9E-27.3f	S. Owens	103	4	709	11.84	697	6-28	
9E-29.5a	R. Geltz		4	739	33.23	706	6-28	
9E-31.8d	L. Baumann	125	4	740	39.40	701	6-30	
9E-32.8f	A. Swenson	100	4	752	45.06	707	6-22	
9E-33.5b	A. Strong	94	4	727	28.22	699	6-22	
9E-34.6e	E. Frega	85		714	17.53	696	6-28	
9E-35.1a	Elmhurst-Chicago Stone Co.	273	6	700	27.0	673	3-14	Well No. 2
9E-35.4b	Ill. Municipal Water Co.	256	10	690	1.50	689	6-28	Village of Warrenville, Well No. 4
9E-36.5d	J. Sass		4	750	61.70	688	6-29	
10E-1.2g	F. Galfans	160	5	733	41.67	691	8-1	
10E-3.2d	W. Mathews		5	771	63.59	707	8-9	
10E-7.2c	J. Bertrand	180		772	64.40	708	8-5	
10E-9.2f	City of Wheaton	341	20	750	54.0	696	6-29	Well No. 4
10E-11.7c	Village of Glen Ellyn	352	12	759	91.0	668	6-6	Village Well No. 2
10E-12.4a	Glen Oak Country Club	202	16	688	30.0	658	7-8	Well No. 2
10E-12.4c	Glen Oak Country Club	212	16	700	22.0	678	7-8	Well No. 3
10E-12.5c	Glen Oak Country Club	130	6	710	42.77	667	7-8	Well No. 1
10E-13.1c	J. Ludwig	100	4	698	17.79	680	8-18	
10E-15.1b	Village of Glen Ellyn	422	20	770	96.0	674	6-6	Well No. 4
10E-16.6c1	City of Wheaton	175	10	749	54.0	695	4-26	Well No. 1
10E-17.8a	Polo Drive & Saddle Road Water Co.	175	8	740	38.0	702	4-8	
10E-18.6c	DuPage County Home	64	6	720	26.47	694	6-29	
10E-19.2g	Franciscan Sisters Home	330	10	740	31.0	709	4-19	Well No. 1
10E-19.3g	Franciscan Sisters Home	325	10	735	29.0	706	4-19	Well No. 2
10E-19.4h	St. Francis High School	252	8	730	30.0	700	4-19	
10E-20.1c1	R. Huggins		5	735	35.67	699	8-19	
10E-20.1c2	Tee & Green Water Assoc.	198	8	740	35.0	705	4-21	
10E-20.2c	Chicago Golf Club	165	6	740	43.3	697	8-19	Well No. 1
10E-23.2c	E. Turek	130	5	740	60.63	679	8-19	
10E-24.8b	Moeller	135	5	720	38.04	682	8-19	
10E-25.2b	C. Gray	172	5	733	57.95	675	8-19	
10E-28.3f	Tenzinger	145	4	752	57.94	694	8-19	
10E-30.3h	H. H. Ballard	150	5	751	39.49	712	6-29	
10E-31.1h	Arrowhead Golf Club	158	4	748	62.0	686	4-20	Well No. 2
10E-33.2c	R. D. Hayes	120	3	741	61.78	679	8-19	
10E-34.3d	Morton Arboretum	250	12	748	82.0	666	6-6	Well No. 3
10E-34.4d	Morton Arboretum	250	12	758	82.0	676	6-6	Well No. 4
10E-36.4f	W. R. Johnson		3	710	32.34	678	8-19	
11E-2.7f	Elmhurst-Chicago Stone Co.	190		690	190	500	8-1	Stone Quarry

Well number	Owner	Depth of well (ft)	Casing diameter (in)	Surface elevation (ft above sea level)	Depth to water (ft)	Water level elevation (ft above sea level)	Date of measurement 1960	Remarks
DUP—								
39N11E-3.1i	Cities Service Oil Co.		5	687	58.4	629	7-24-59	
39N11E-3.2f	Elmhurst Park District	100	4	673	70.0	603	8-1	
39N11E-3.6h	C. Glimco	70		693	42.66	650	8-17	
39N11E-5.3d	H. Melton	100		712	32.65	680	8-1	
39N11E-10.4g5	Wander Co.	197	14	675	19.0	656	8-15	Well No. 5
39N11E-10.8e1	Village of Villa Park	285	8	702	55.0	647	5-2	Village Well No. 3
39N11E-10.8e2	Village of Villa Park	251	12	702	55.0	647	5-2	Village Well No. 4
39N11E-13.3g	City of Elmhurst	290	8	710	88.0	622	8-13	City Well No. 7
39N11E-13.6c	J. Livingston	110	5	677	25.44	652	7-11	
39N11E-13.7b	Swaim & Skinner	110		667	12.89	654	7-11	
39N11E-14.8a	H. E. Voss	117		667	2.94	664	7-11	
39N11E-14.8e	J. Weskrna	155	6	672	19.58	652	7-11	
39N11E-16.4d	G. Wyns			700	29.36	671	8-23	
39N11E-17.2c	Pullman			708	26.65	681	8-18	
39N11E-18.5d	I. Frey	110		720	40.18	680	8-18	
39N11E-21.5e	D. Helms			725	51.26	674	7-13	
39N11E-22.4c	G. Kurtz	120		685	25.65	659	7-13	
39N11E-23.1h	V. Castelli	100		665	13.90	651	7-11	
39N11E-24.2g	J. H. Jones	350		690	39.23	651	6-24	
39N11E-24.3a2	American Can Co.	245	10	682	33.0	649	7-11	Well No. 1
39N11E-25.4d	E. Mulac	165	5	670	21.42	649	7-11	
39N11E-25.6e	Butler Co.	160	5	675	33.99	641	7-13	
39N11E-26.3b	Butler Co.		8	665	25.44	640	7-11	
39N11E-28.7d	C. Ballinger	117	5	720	45.45	675	7-13	
39N11E-33.1e	Midwest Country Club	170	8	720	62.0	658	7-12	Well No. 1
39N11E-33.2d	D. Kitzing		5	733	61.16	672	7-13	
39N11E-34.7h	G. Mueller	105	4	715	51.01	664	7-13	
39N11E-35.1d	J. Telander	90	5	672	28.28	644	7-11	
39N11E-36.4f	M. Carlson	45	4	650	12.37	638	7-11	
40N9E-1.2h	G. Anagnost	164		790	51.39	739	7-18	
40N9E-3.7b	Carrol			810	41.65	768	7-1	
40N9E-6.8c	R. Haas	95	5	765	21.82	743	7-1	
40N9E-14.5b	W. Niemeyer		5	768	30.02	738	7-8	
40N9E-19.4b	Hammond	120	5	758	31.37	727	7-6	
40N9E-21.5c	K. Bierkamp			783	33.29	749	7-15	
40N9E-24.7g	W. Bierman		5	782	42.06	740	7-8	
40N9E-26.3e	Fair Oaks Farm		5	788	51.35	737	7-6	
40N9E-28.4b2	Christ the King Seminary	160	8	788	47.0	741	7-6	Well No. 2
40N9E-30.3c	J. Koselka	119	5	752	48.55	703	7-1	
40N9E-32.5g	Kawneer Products Co.	270	12	755	84.5	671	8-7	Well No. 2
40N9E-32-6g	Kawneer Products Co.	271	12	755	60.0	695	6-9	Well No. 1
40N9E-32.6h	Owens-Illinois Closure & Plastics Div.	300	20	753	76.0	677	2-9	Well No. 3
40N9E-33.1a	Mr. Binder	150	6	775	51.39	724	7-6	
40N9E-34.1a	Wheaton College Academy	220	6	762	38.21	724	7-6	
40N9E-35.1f	O. C. Hiltman	160	6	762	37.53	724	7-8	
40N9E-35.3g	Sidwell Studios	192	8	748	26.0	722	7-6	
40N9E-35.8h	G. Reed	100	5	740	5.01	735	7-6	
40N9E-36.4c	L. Peters		6	749	27.39	722	7-8	
40N10E-1.4d	W. Wiebe	155	5	733	27.16	706	7-26	
40N10E-2.4d	J. Peterson	150	5	735	19.29	716	7-26	
40N10E-3.4e2	Village of Roselle	183	10	770	54.0	716	3-22	Village Well No. 2
40N10E-4.5e	R. Wieble	190	5	805	63.13	742	7-26	
40N10E-8.6f	E. Hasse	155	4	783	30.64	752	7-26	
40N10E-10.8h	J. Anderson	155	5	788	49.21	739	7-26	
40N10E-12.5b	Medinah Country Club	145	6	700	22.0	678	7-8	Well No. 1
40N10E-13.1g	Mr. Parks	132	5	692	9.13	683	7-28	
40N10E-14.4c	Glendale Country Club	212	8	760	62.27	698	7-8	Well No. 2
40N10E-15.4e	E. W. Dunteman	130		748	28.63	719	7-29	
40N10E-16.1e	Mr. Knobloch	187	5	798	74.10	724	7-29	
40N10E-16.4a	Sod Farm Nursery	370	10	792	47.19	745	8-1	Well No. 3
40N10E-17.5e	P. Benshoof	152	4	794	30.78	763	7-29	
40N10E-18.1d2	W. H. Kurth	160	4	790	39.23	751	7-8	
40N10E-20.5f	J. Klein	160	4	772	36.89	735	7-29	

Well number	Owner	Depth of well *(ft)*	Casing diameter *(in)*	Surface elevation *(ft above sea level)*	Depth to water *(ft)*	Water level elevation *(ft above sea level)*	Date of measurement 1960	Remarks
P—								
10E-20.6e1	Allied Cement Co.		5	767	19.08	748	7-8	Well No. 1
10E-22.8c	R. Stark	170	4	792	62.54	729	8-1	
10E-23.4b	Unknown		5	710	6.17	704	8-1	
10E-24.8h	P. Garriott	172	5	749	43.60	705	7-28	
10E-25.5e	T. Karlanak	183	5	728	24.02	704	8-1	
10E-26.4e	B. Moty	185	4	740	25.52	714	8-1	
10E-27.4b	E. V. Rust	150	4	812	64.52	747	8-8	
10E-28.5a	M. F. Downer	121	4	812	81.36	731	8-9	
10E-31.2g	Carol Stream Utilities Co.	335	10	764	40.0	724	7-8	Village of Carol Stream, Well No. 1
10E-35.7f	J. Komala	135	5	750	34.27	713	8-1	
11E-3.3h	K. Grooms	139	5	682	23.07	659	8-16	
11E-4.1e	G. Kraiss	130	4	712	41.73	670	8-16	
11E-5.2h	W. Ray		5	687	11.33	676	7-27	
11E-6.6e	J. Gronewold	154	4	724	36.44	688	7-27	
11E-7.1b	R. Bensen	128	6	700	26.00	674	7-28	
11E-8.6c	Village of Itasca	190	12	700	22.0	678	5-9	Village Well No. 5
11E-8.6e	Village of Itasca	200	12	690	14.0	676	7-5	Village Well No. 3
11E-10.8e	J. Mahoney	128	4	702	36.67	665	8-16	
11E-11.1h2	Flick-Reedy Corp.	125	8	665	27.66	637	8-16	Well No. 2
11E-13.4e	S. Kivo	135	5	667	33.48	634	8-15	
11E-14.5c	C. Whitney	155		680	45.40	635	8-16	
11E-15.8g	E. Koscik	151	5	712	56.17	656	8-16	
11E-16.5g	M. Spatola	117	4	693	26.65	666	8-16	
11E-17.3h	Mr. Hemmi	86	5	703	18.90	684	7-28	
11E-18.5e	R. Ross	95		720	30.94	689	7-28	
11E-19.6c	O. Ryman		4.5	750	52.72	697	8-1	
11E-21.4b	W. Byrne	150		683	14.49	669	8-16	
11E-23.7g	F. Roy			683	39.85	643	8-16	
11E-24.4b	River Forest Country Club	219	10	660	24.0	636	8-16	Well No. 2
11E-24.6e	D. Imes	125	4	665	38.67	626	8-17	
1E-25.5f	Citizens Utilities Co. of Illinois	226	12	680	42.0	638	2-2	Country Club Highlands Subdiv., Well No. 1
1E-27.4g	J. Hemmis			690	34.10	656	8-16	
1E-29.2a	W. Rosenwinkel	120		688	5.29	683	8-1	
1E-30.3g	L. Heinrich	195	6	727	36.76	690	8-1	
1E-31.4a	T. Manck	145	4	720	27.76	692	8-1	
1E-33.7g	Village of Addison	250		710	31.0	679	7-5	Village Well No. 4
1E-34.7d	R. Saatkamp	90		680	21.70	658	8-17	
1E-35.4e	F. Magnuson	185	5	698	55.24	643	8-17	
1E-36.8f	A. Rosenthal	138	5	683	56.00	627	8-17	

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Preliminary Report on the GROUND-WATER RESOURCES OF THE HAVANA REGION IN WEST-CENTRAL ILLINOIS

William H. Walker
Robert E. Bergstrom
William C. Walton

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PRELIMINARY REPORT ON GROUND-WATER RESOURCES OF THE HAVANA REGION IN WEST-CENTRAL ILLINOIS

William H. Walker, Robert E. Bergstrom,
and William C. Walton

ABSTRACT

Pleistocene sand and gravel deposits underlying the Havana region of west-central Illinois constitute one of the largest underdeveloped aquifers in the state. The deposits are more than 100 feet thick in most places and were laid down in a wide lowland formed at the junction of several large valleys excavated in bedrock. Where they fill bedrock channels, the deposits locally exceed 150 feet thick.

The main aquifer consists of Sankoty Sand (Kansan) and overlying Wisconsinan sand and gravel outwash in much of the region. To the east, where Wisconsinan outwash terminates against Wisconsinan and Illinoian upland tills, the aquifer consists essentially of the Sankoty Sand.

Pennsylvanian and Mississippian rocks underlie the Pleistocene deposits and are not developed as a source of ground water where sand and gravel aquifers are present. Rocks below the Mississippian contain water too highly mineralized for most domestic purposes.

The average coefficient of permeability of the main sand and gravel aquifer ranges from about 2,000 to 15,000 gallons per day per square foot. Properly designed and developed wells should yield 1 million gallons per day with moderate drawdowns. Recharge from precipitation is received at the average rates of 490,000 gallons per day per square mile in areas where the granular deposits of the aquifer extend to the surface and 270,000 gallons per day per square mile in areas where layers of till overlie the aquifer. The quantity of water stored in the Pleistocene unconsolidated deposits is estimated to be about 7.2×10^{12} gallons.

Total ground-water pumpage in the Havana region was about 21 million gallons per day in 1960; 85 percent of this was pumped for industrial use in the extreme northern part of the region. Pumpage for supplemental irrigation was low in 1960 but is expected to increase at a rapid rate. In most of the region, pumpage has not appreciably affected the water table.

The water-yielding character of the sand and gravel deposits, recharge rates from precipitation, and possibilities for induced infiltration of surface water indicate that the potential yield of unconsolidated deposits in the Havana region may be about 350 million gallons per day.

INTRODUCTION

large undeveloped ground-water reservoir under-
an area along the Illinois and Sangamon Rivers in
-central Illinois (fig. 1). The area is called the Ha-
region in this report. The reservoir consists of
. deposits of sand and gravel saturated with ground
r that is of good quality and readily available to
. The area is geographically situated near the popu-
n centers of Illinois and of the United States and
essible to local and distant markets by river, rail,
way, and air. Mineral resources needed in many in-
ial processes are close at hand. Soils of the area
bountiful field and truck-garden crops when sup-
ntal irrigation practices are employed. Although
ased demands for industrial and agricultural water in recent years have stimulated the development of available ground-water supplies, the ground-water reservoir has much greater potential.

Purpose and Scope

In anticipation of an increased rate of industrial, municipal, and agricultural development in the Havana region, the Illinois State Water Survey and the Illinois State Geological Survey began a detailed ground-water investigation of the area in 1957.

This report is based on data collected during the investigation and additional data on file at the Illinois State Water Survey and the Illinois State Geological Survey and in published reports. It presents geologic

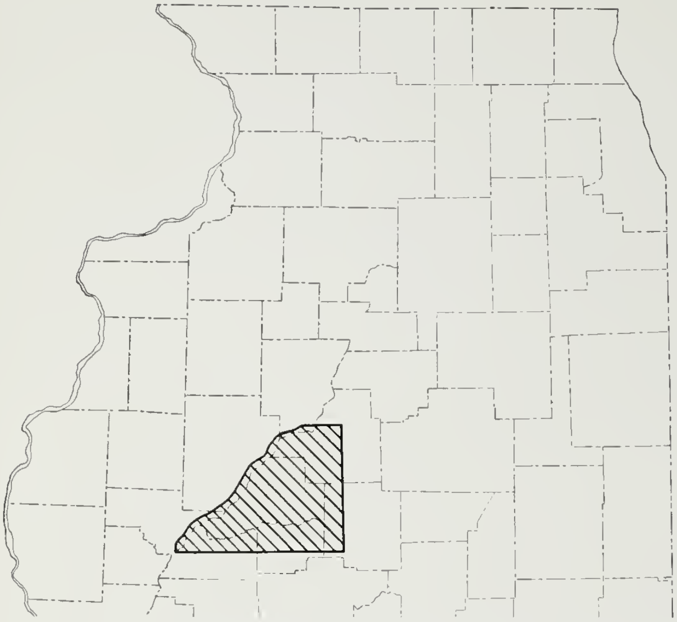


Fig. 1. Location of the area covered by this report and referred to as the Havana region.

and hydrologic information, the geologic history of the area, present hydrologic conditions, and effects of possible future development on the ground-water resources of the region. Special emphasis is placed on the extensive unconsolidated sand and gravel deposits, which are the principal aquifers in the region, and their potential yield is evaluated. The geology and hydrology of the bedrock formations are discussed only briefly as these formations contain limited quantities of ground water, and it is of relatively poor quality. Data on water levels, pumpage, well construction features, water temperature, mineral quality of water, well-production and aquifer tests, and other hydrologic information were collected by the State Water Survey. Well logs, drilling samples, geophysical logs, and other geologic information were collected by the State Geological Survey.

Although this report summarizes recent knowledge of ground-water conditions in the region, it is a preliminary report in the sense that it is part of a continuing study of the ground-water resources, and its conclusions and interpretations may be modified and expanded as more data are obtained.

Base maps of the area studied were drawn from U.S. Geological Survey topographic maps (fig. 2) and from Illinois State Division of Highways county highway maps. All elevations mentioned in this report were taken from these maps.

Previous Reports

Although this is the first detailed ground-water report of the Havana region, its large ground-water resources have been mentioned in geologic reports by Horberg (1950), and Wanless (1957). Ground-water conditions in the vicinity of Peoria and Pekin on the north edge of the study area were described by U (1908) and by Horberg, Suter, and Larson (1950 description of municipal and industrial wells in u the Pekin area was given in Illinois State Water Su Bulletin 33 (1940, p. 81–114). A brief discussion o occurrence of ground water in the area appeared report by Selkregg and Kempton (1958).

The major geologic reports that cover or contain r ences to the region, in addition to those cited above a study of the Peoria Quadrangle by Udden (1912) stratigraphic investigations of the glacial deposit Frye and Willman (1960), Leonard and Frye (1 and Leighton and Brophy (1961). Root (1936) Bredehoeft (1957) reported in detail on the area ology and bedrock topography, and maps by H. A. S (prepared in 1930 under the direction of George E. blaw and kept on file at the State Geological Sur show sand and gravel resources of Tazewell and M Counties.

Quadrangle topographic maps of the region have prepared cooperatively by the United States Geolo Survey and the Illinois State Geological Survey (fig Wanless (1957) published geologic maps of the Be town, Havana, and Glasford Quadrangles, and the P Quadrangle was mapped by Udden (1912).

Well-Numbering System

The well-numbering system used in this repo based on the location of the well or test hole, whi identified by township, range, and land section.

The well number consists of five parts: county a viation, township, range, section, and coordinate w the section. Sections are divided into squares one-ei of a mile long that correspond to a quarter of a qu of a quarter section and contain 10 acres. A normal tion of 1 square mile contains 8 rows of these squ

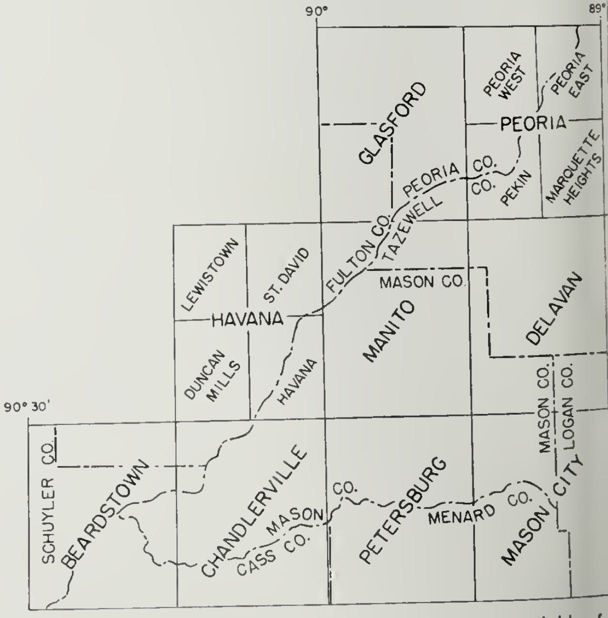
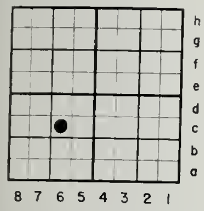


Fig. 2. Index of quadrangle topographic maps available fo Havana region.

odd-sized section contains more or fewer rows. Rows numbered from east to west and lettered from south orth as follows:



Sec. 27, T.24N. R.7W.
Tazewell County

e number of the well shown in section 27 above is 24N7W-27.6c. Where there is more than one well 10-acre square, wells are identified by arabic num- after the lower case letter in the well number: 24N7W-27.6e2.

breviations used for counties are:

CSS	Cass	MSN	Mason
FUL	Fulton	PEO	Peoria
LOG	Logan	SCH	Schuyler
MEN	Menard	TAZ	Tazewell

Acknowledgments

e authors appreciate the courteous and generous ance of all who contributed information and aided in the collection of field data for this report. Much of the basic data was collected by R. R. Russell, A. R. Knodel, T. A. Prickett, and W. H. Baker of the Water Survey, and L. A. Reed and Bruce Adamson of the Geological Survey. J. D. Bredehoeft and L. D. McGinnis of the Geological Survey conducted seismic refraction studies in the area. Grover H. Emrich assisted in the preparation of some of the geologic sections and illustrations. Suggestions and criticisms were given by G. B. Maxey, T. E. Larson, George E. Ekblaw, H. F. Smith, and many others from both Surveys during the course of the investigation.

Velmar W. Davis, agricultural economist, U.S. Department of Agriculture, and Ray Lane, work unit conservationist, U.S. Soil Conservation Service, supplied much valuable information on agricultural practices, supplemental irrigation methods employed, and quantities of water used each year for agricultural purposes in the region.

This report would have been impossible without the generous cooperation of municipal officials, industries, engineers, and water well contractors who provided information on wells, water levels, and pumpage.

GEOGRAPHY

Location and Extent of Havana Region

Havana region includes Mason, southwestern ell, western Logan, northern Menard, and northern Counties, and the strips of Peoria, Fulton, and ler Counties adjacent to the Illinois River (fig. lies between parallels 40° 00′ and 40° 35′ N lati- nd meridians 89° 30′ and 90° 30′ W longitude).

ailed hydrologic studies were made within the Ha- region in an area of approximately 720 square in Tazewell and Mason Counties. This area is ed on the west by the Illinois River, on the south Sangamon River, and on the east by ground- divides that trend roughly east-northeast in the y of Kilbourne, Mason City, San Jose, and Dela- nd northwest and north near South Pekin (fig. 3).

principal cities within the Havana region are Delavan, Havana, Mason City, and Beardstown). Federal Highway 136 and State Highways 9, 78, 97, 121, and 122 pass through the region, as Illinois Waterway and the Chicago and Illinois d, Illinois Central, Gulf Mobile and Ohio, and o and North Western railroads. In addition to ailroads serving the interior part of the region, chison, Topeka and Sante Fe, New York Central, ledo, Peoria and Western railroads serve Pekin, e Baltimore and Ohio and Chicago, Burlington uincy railroads serve Beardstown.

Topography

The Havana region is primarily a wide, low, rolling, roughly triangular sandy plain along the Illinois River, bordered on the east by glaciated uplands, on the south by the south bluff of the Sangamon River and Salt Creek, and on the west by the west bluff of the Illinois River. It includes three main physiographic areas (fig. 4): (1) the floodplains of the Illinois, Sangamon, and Mackinaw Rivers and Salt Creek; (2) the wide sand-ridged terraces east of the Illinois River; and (3) the loess-covered Illinoian drift upland in southeastern Mason County. Elevations in the region range from about 430 feet above mean sea level on the Illinois River floodplain near Beardstown to 736 feet in the uplands west of Mason City.

The Illinois River emerges from a narrow gorge north of Pekin into a floodplain 3 to 4 miles wide that has an average elevation of about 435 feet above sea level. It narrows downstream from Beardstown. The floodplain is marked by low natural levees, shallow lakes representing former river channels and meanders, alluvial fans of tributary streams, and river bars. The gradient of the river is slightly less than 2 inches per mile. In contrast to the tightly meandering natural courses of the Sangamon River and Salt Creek prior to artificial straightening, the course of the Illinois River in its floodplain is relatively straight to gently curving.

Bordering the Illinois River floodplain on the east is a terrace belt 3 to 17 miles wide. The terraces were formed during glacial stages when flow of the river was greater than it is today. The terraces are named, from lowest to highest, Beardstown, Bath, Havana, and Manito (Wanless, 1957). The Beardstown Terrace is about 445 feet above sea level at Beardstown, 10 feet higher than the floodplain, and is marked by large abandoned river meanders. The Bath Terrace slopes from an elevation of about 465 feet above sea level near Havana to about 445 feet east of Beardstown. Dunes or sand ridges on the Bath Terrace rise to about 500 feet above sea level. The Havana Terrace slopes from an elevation of about 485 feet near Pekin to about 465 feet south of Bath. It has an elevation of about 495 feet along Crane Creek and about 490 feet along Quiver Creek. Dunes or sand ridges are common on the part of the terrace near the Illinois River. The Manito Terrace is the most extensive terrace in the Havana region. From a 530-foot elevation west of Delavan it descends to 510 feet just west of Manito and to 490 feet at Kilbourne. Linear to arcuate sand ridges, which rise as high feet above the general level, occur in extensive trac the terrace.

Rising above the Manito Terrace, from San Jose s westward to near the mouth of Crane Creek, is a mocky tract of Illinoian sandy drift. Many hills ridges between San Jose and Mason City stand fro to more than 100 feet above the surrounding level. roughest topography is found in the narrow uplan tween the Sangamon River and the lower part of Creek south of Easton where steep sand hills have tions of more than 700 feet above mean sea level, or than 200 feet above the Sangamon River flood Southeast of Delavan the Illinoian sandy drift tra bounded by the bold Wisconsinan morainal front.

Drainage

The Illinois River, with an average flow of cubic feet per second (cfs) at Kingston Mines and cfs at Meredosia, 15 miles south of Beardstown, re all the drainage of the Havana region. Some o

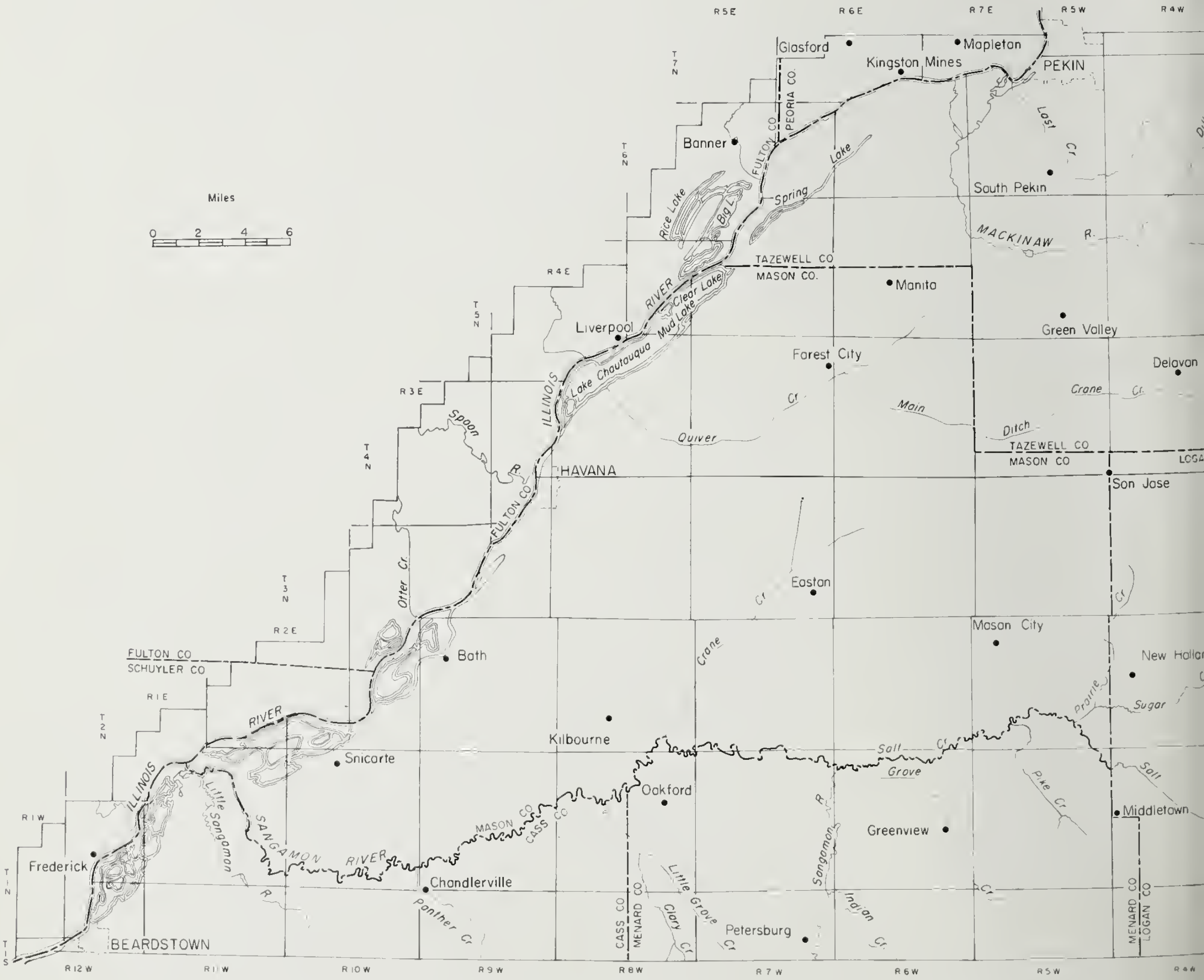


Fig. 3. Main geographic features and land divisions of the Havana region.

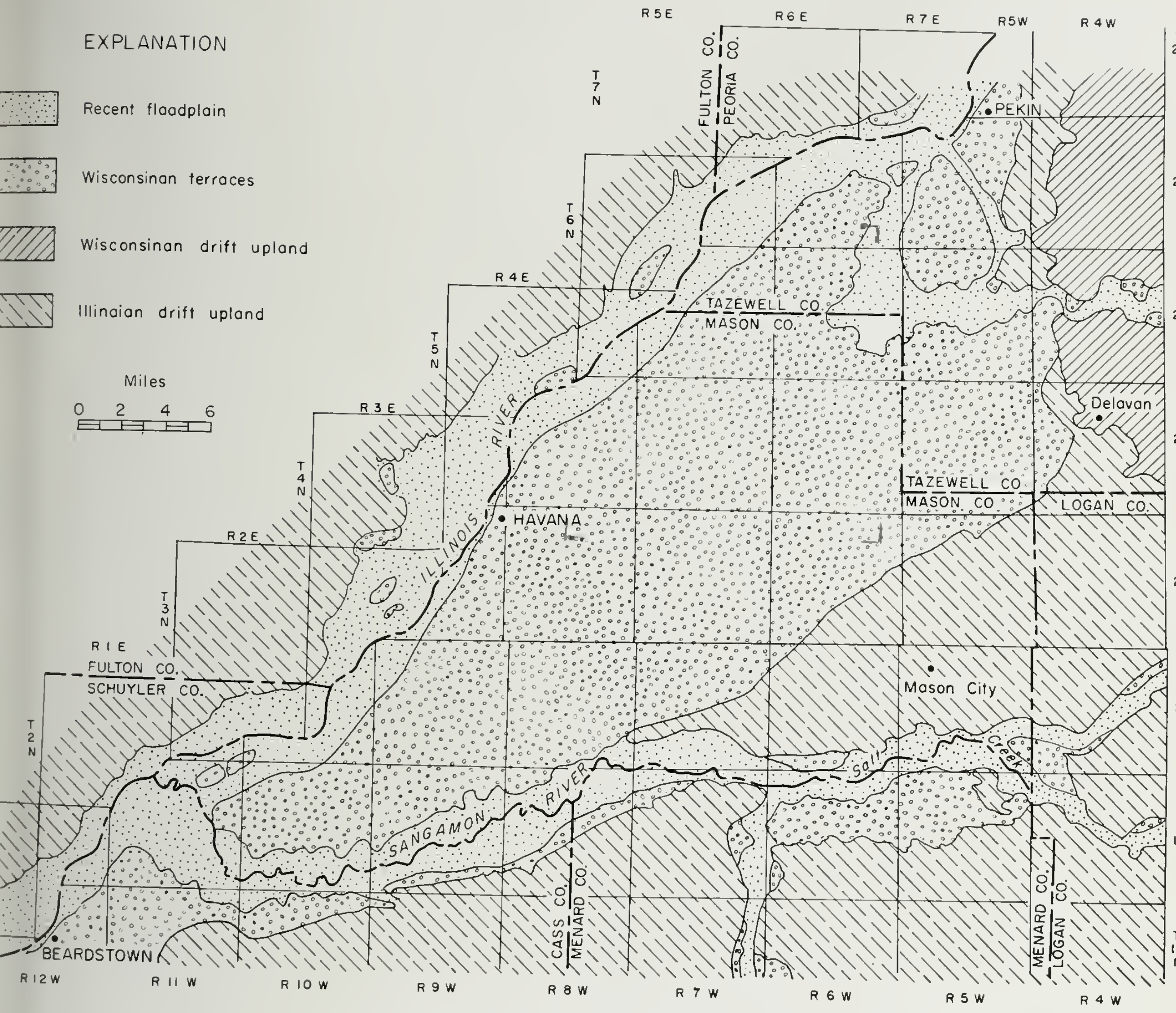


Fig. 4. Major physiographic areas of the Havana region.

ge passes first into the Mackinaw or Sangamon s or into Salt, Crane, or Quiver Creeks. Many ns emerge from the uplands west of the Illinois south of the Sangamon-Salt system, and north of ackinaw River, but within the valley bottoms and s in the main region studied there are few streams. alley bottoms have extensive lakes and marshes. sandy terraces extensive ditches have been con- d along Crane and Quiver Creeks to improve ge conditions on flat lands where the water table low.

Climate

ummary of 1958 climatological data collected at eater Peoria Airport at Peoria, Illinois, just north Havana region is given below (U.S. Weather Bu- 959).

climate of this area is typically continental as shown by riability and the wide range of temperature extremes.

Monthly mean temperatures range from 25 degrees during January to 76 degrees during July with an annual average of 51 degrees. The average January has 28 days with freezing temperatures but only 4 days with readings as low as zero. Conversely the average July has 11 days with 90 degrees or higher but only 1 day with a reading as high as 100. Illustrating the extreme conditions that have occurred, the single year of 1936 had 17 days with temperatures 100 or higher in July while the early part of that same year had 26 zero days in a 31-day period. 1936 also had the absolute maximum record of 113 set on July 15 but the absolute minimum of −27° dates back to January of 1884. Autumn is considered the most pleasant time of the year, usually culminating in the ''Indian Summer'' period of warm and dry conditions in late October or early November.

The average freeze-free period covers 189 days from April 15 to October 20. Past records indicate that general freezing conditions have occurred as late as May 9 in 1945 and as early as September 26 in 1928.

The normal annual precipitation is 35.18 inches with individual years ranging from 23.18 inches in 1910 to 53.26 inches in 1858. May is normally the wettest month with 3.98 inches while the driest summer month is August. There are no wet or dry seasons but precipitation is heaviest during the growing

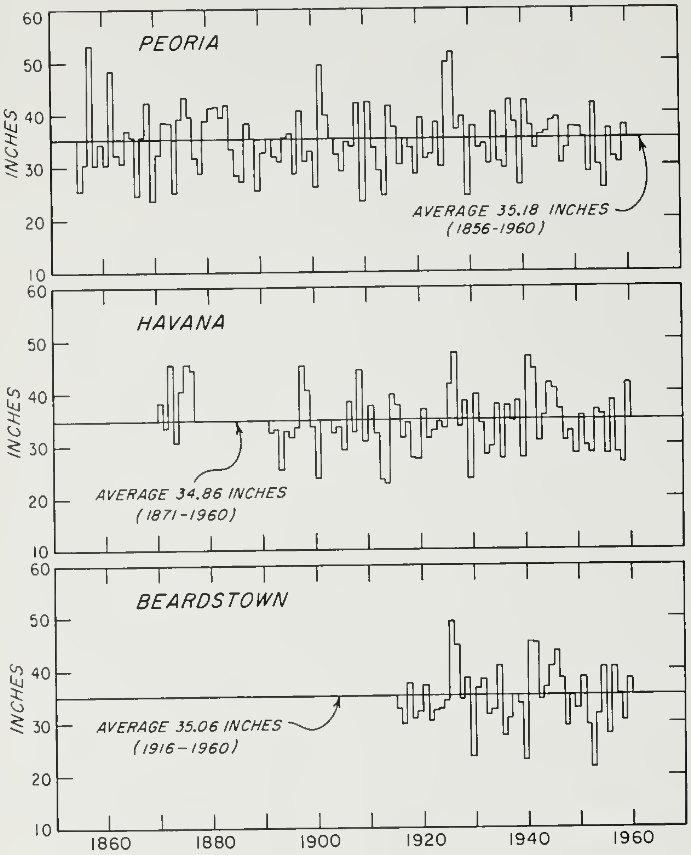


Fig. 5. Annual precipitation at Peoria, Havana, and Beardstown, 1856-1960.

season and at a minimum during mid-winter. The wettest month on record was September 1911 with 12.30 inches, but nearly half that much has fallen in a single 24-hour period (5.52 inches in 24 hours in May 1927). It is also interesting to note that the maximum 1-hour rainfall (2.60 inches) is almost half as great as the maximum in 24 hours.

Annual snowfall averages 21.6 inches and has ranged from 6.0 inches in 1928 to 45.7 inches in 1926. More than 70% of the annual snowfall occurs during the three months of December, January, and February. Snow has occurred as late as May 9 and as early as September 25 when one inch fell in 1942. The heaviest single storm of record brought 18 inches during the last two days of February in 1900.

Prevailing winds at Peoria are from the south during all months except February when they are from the northwest. This differs from the usual pattern in this general area where prevailing winds are from the south or southwest in summer and from the northwest during the four or five colder months. March is the month with the most wind while August has the least. Thunderstorms are reported on an average of 49 days per year with activity reaching a peak in June. The months of April through September average 5 or more thunderstorm days each while December is the month with fewest thunderstorms. Heavy fog is rare in this area with a peak occurrence of only 2 days per month during the winter season. Humidity varies considerably depending upon the direction of wind movement. The driest air moves in from the west or northwest while easterly and southerly winds bring more humid conditions. Relative humidity is lowest during the afternoons and is higher at and during precipitation. Sunshine is unevenly distributed during the year and is greatest during July when days are long and cloudiness is at a minimum. December is the darkest month and averages only 37% as much bright sunshine as does July.

Graphs of annual and normal monthly precipi
for the years of record at Peoria, Havana, and B
town (figs. 5 and 6) indicate that the mean annua
cipitation in the Havana region is about 35 inches
the Havana station during a normal year recordin
inches less than Beardstown and 0.32 inches less
Peoria. Normal monthly precipitation at the
stations is similar, but slight differences are evide
tween the Peoria records and those for Havana
Beardstown. At Peoria the normal monthly pre
tion increases from a low in January to a high in
remains high during June and July, drops abrup
August, and increases noticeably in September
decreasing during the remainder of the year. At th
vana and Beardstown stations, however, the yearl
and high values occur a month later, with the first a
decrease occurring a month earlier than at the
station (fig. 6).

The annual maximum precipitation expected o
5 years is 40 inches and the minimum is 29 inches
maximum expected once in 50 years is 50 inches a
minimum 24 inches (Atlas of Illinois Resources,

Population

In 1960, approximately 79,000 people lived in th
vana region, about a third of them in Pekin in Ta
County.

Mason County had a population in 1960 of
(table 1), nearly three-fourths of which was cla
as rural. As in many other dominantly rural ar
Illinois, the population of Mason County has de
slightly in the past decade. In contrast, the popu
of most cities and dominantly urban counties in t
gion rose during the same period. For exampl

Table 1. Population of Counties and Selected Municipalities
Havana Region, 1890-1960

(From "U.S. Census of Population, 1960. Number of Inhabi
Illinois.")

	1890	1920	1930	1950
County				
Cass	15,963	17,896	16,934	15,097
Logan	25,489	29,562	28,863	30,671
Mason	16,067	16,634	15,115	15,326
Menard	13,120	11,694	10,675	9,639
Tazewell	31,338	38,540	46,082	76,165
Town				
Bath	384	408	346	423
Beardstown	4,226	7,111	6,344	6,080
Delavan	1,176	1,191	1,084	1,248
Easton	....	456	403	371
Forest City	....	314	269	278
Green Valley	....	446	454	503
Havana	2,525	3,614	3,451	4,379
Kilbourne	....	393	393	374
Manito	444	758	711	869
Mason City	1,869	1,880	1,941	2,004
New Holland	....	457	353	343
Pekin	6,347	12,086	16,129	21,858
San Jose	307	566	486	562
South Pekin	....	1,362	1,222	1,043

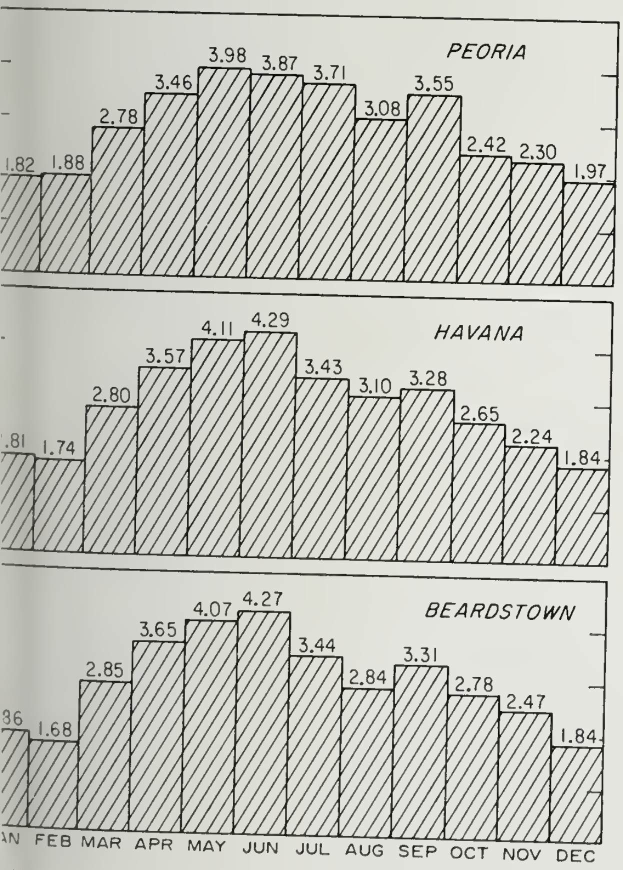
pulation of Tazewell County grew 30 percent between 50 and 1960, and 69.9 percent of its 1960 population s urban.

Of the total population of 79,000, about 52,000 were ved by municipal water systems and 27,000 by private stems. Nearly all water supplies in the area are obned from sand and gravel aquifers.

Economy and Natural Resources

The economy of the Havana region is based primarily agriculture, with support from manufacturing, min-, transportation, power generation, and recreation. sh-grain farming is the principal enterprise in the ion (Ross and Case, 1956, p. 45–48). As a group, the ms are among the largest in the state, averaging more n 200 acres, and use from 85 to 90 percent of the land a. In Mason County, there were 1157 farms in 1950, which 849 were classified as cash-grain, 111 as livek, and 83 as general. Thirty-five percent of the crop d was in corn, 17 percent in wheat, 10 percent in soyns, and 9 percent in oats. The sandy soils of the area favor the growth of melons, potatoes, and other k crops, and conifers, all of which supplement the me received from grain.

f the total land area within the region, about 50 peris composed of terraces, 20 percent is floodplain, and percent is upland (fig. 4). Light to dark sandy soils with coarse-textured, highly permeable subsoils predominate on the terraces; dark to light fine-grained soils with medium to fine-textured, poorly to moderately permeable subsoils occur in the valley bottoms; and dark soils with medium-textured, moderately permeable subsoils occur on the uplands. The upland soils, fairly high in organic matter from the former growth of prairie grasses, are moderately to highly productive. Dune sands, which occupy more than 20 percent of the land area in Mason County, are generally left in timber because they are very low in organic matter and are susceptible to wind erosion if cultivated intensively.



Normal monthly precipitation in inches at Peoria, Havana, and Beardstown.

The sandy soils require frequent moisture replenishment during the growing season. The availability of large ground-water supplies has led to the increasing use of supplemental irrigation in Mason County, and it is likely that irrigation will continue to increase in the future.

Industry in the region is concentrated around Pekin. The bulk of the manufacturing is in the processing of food and kindred products, or in such related lines as packaging.

The Illinois River and the many lakes of the floodplain provide additional economic benefits to the region. More than 17 million tons of shipping passes up and down the Illinois Waterway annually, and storage facilities for grain, coal, sand and gravel, and petroleum products are found at Beardstown, Havana, Liverpool, Kingston Mines, and Pekin. Electric utility power plants along the river near Pekin and at Havana have a capacity of 550 thousand kilowatts and an annual electric power output of more than 1.5 billion kilowatt hours. Recreational areas, with facilities for hunting, fishing, boating, and swimming are plentiful along the river.

Coal mining is of sufficient magnitude in adjoining Fulton, Peoria, and Schulyer Counties to be of importance to the economy of the Havana region. In 1962 more than 6 million tons of coal was produced having a value greater than 26 million dollars (Busch, 1963, p. 16–23). More than 5 million tons was from Fulton County, presently the third largest coal-producing county in the state. At least five coals of minable thickness are present, including the Springfield (No. 5), Herrin (No. 6), and Colchester (No. 2). Mining is almost entirely by stripping, and vast reserves are known to be present. All the coals in the area belong to the high-volatile bituminous "C" rank. Analyses of coal samples were given by Cady (1935, 1948).

Most of the sand and gravel deposits worked commercially are Wisconsinan outwash, which rises as low terraces above the floodplains of the Illinois and Mackinaw Rivers. The outwash becomes finer downstream, ranging from clean, well sorted gravel near Pekin to fine, sandy gravel and gravelly sand south of Havana. At a few sites in the upland in the San Jose area, sand and gravel pits have been operated in Illinoian deposits.

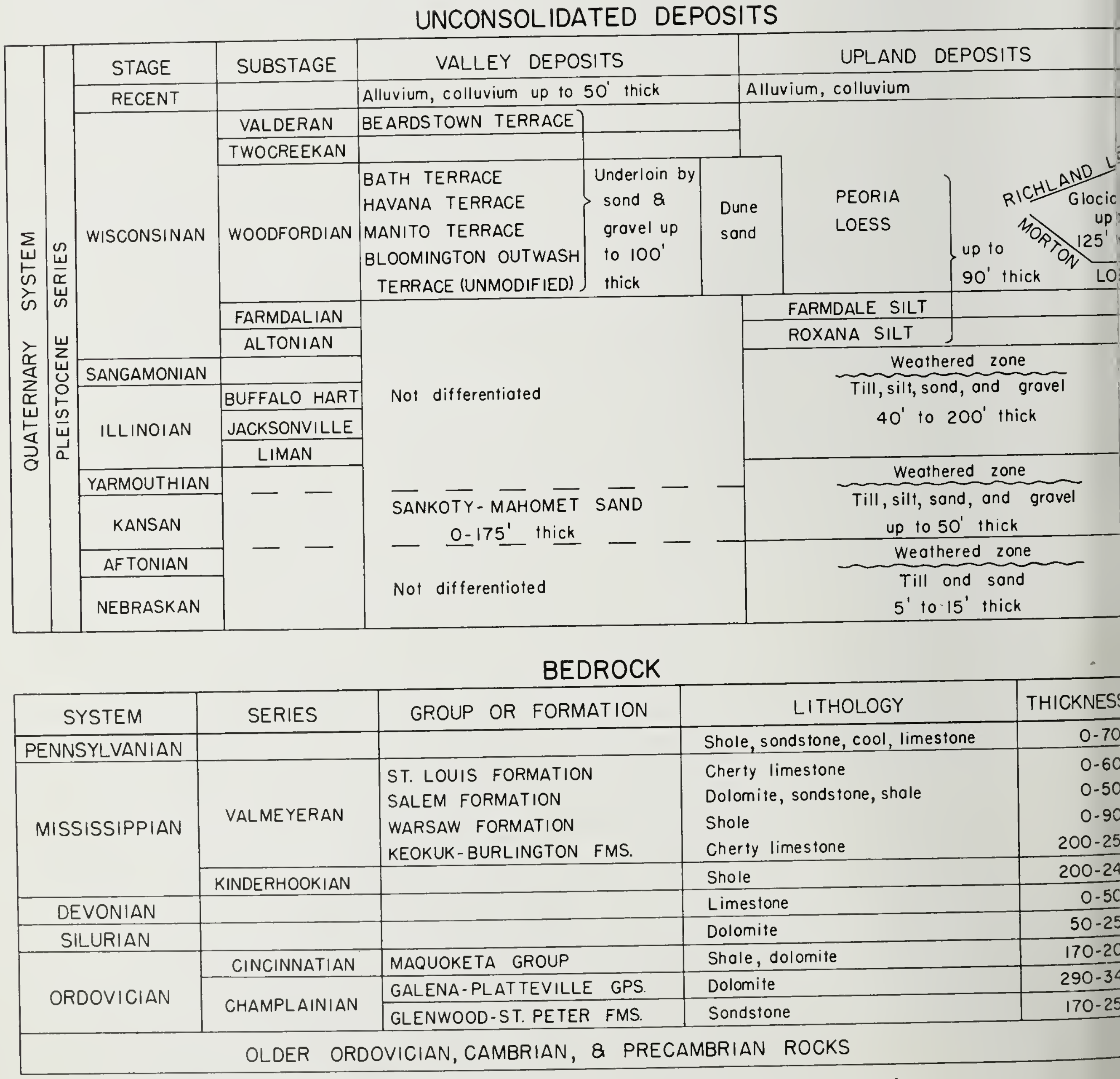
Numerous unsuccessful oil and gas tests have been drilled in the region and the outlook for commercial production is unfavorable.

GEOLOGY

Deposits of sand and gravel in the unconsolidated sediments overlying the layered bedrock supply nearly all the ground water used in the Havana region. The unconsolidated sediments consist of glacial drift, wind-blown silts (loess) and sands, and recent stream deposits.

The drift is differentiated into that deposited directly from the melting ice (till) and that modified by the associated meltwater into glacial river (glaciofluvial) and glacial lake (glaciolacustrine) deposits. *Till* is a mixture of fragments of all sizes with rarely any stratification. It occurs in the form of ridges (end moraines) and intervening undulatory plains (ground moraines). The end moraines were deposited when the melting of the ice was equivalent to the advance of the glacier, so th ice front was temporarily relatively stationary. ground moraines were deposited when the melting ice front exceeded the forward advance of the gla

Glaciofluvial deposits were laid down by melt that was discharged along the front of the ic through crevasses and channels extending back in ice. Rock fragments picked up by the meltwater transported and deposited downstream. Among th forms created by meltwater in the Havana regio *valley trains, outwash plains, crevasse-fill ridges* roughly circular hills called *kames.*



UNCONSOLIDATED DEPOSITS

		STAGE	SUBSTAGE	VALLEY DEPOSITS	UPLAND DEPOSITS
QUATERNARY SYSTEM	PLEISTOCENE SERIES	RECENT		Alluvium, colluvium up to 50' thick	Alluvium, colluvium
		WISCONSINAN	VALDERAN	BEARDSTOWN TERRACE	
			TWOCREEKAN		
			WOODFORDIAN	BATH TERRACE HAVANA TERRACE MANITO TERRACE BLOOMINGTON OUTWASH TERRACE (UNMODIFIED) Underlain by sand & gravel up to 100' thick Dune sand	PEORIA LOESS up to 90' thick RICHLAND L Glacic up 125' MORTON LO
			FARMDALIAN	Not differentiated	FARMDALE SILT
			ALTONIAN		ROXANA SILT
		SANGAMONIAN			Weathered zone Till, silt, sand, and gravel 40' to 200' thick
		ILLINOIAN	BUFFALO HART		
			JACKSONVILLE		
			LIMAN		
		YARMOUTHIAN	— —	SANKOTY-MAHOMET SAND 0-175' thick	Weathered zone Till, silt, sand, and gravel up to 50' thick
		KANSAN	— —		
		AFTONIAN		Not differentiated	Weathered zone Till and sand 5' to 15' thick
		NEBRASKAN			

BEDROCK

SYSTEM	SERIES	GROUP OR FORMATION	LITHOLOGY	THICKNES
PENNSYLVANIAN			Shale, sandstone, coal, limestone	0-70
MISSISSIPPIAN	VALMEYERAN	ST. LOUIS FORMATION	Cherty limestone	0-60
		SALEM FORMATION	Dolomite, sandstone, shale	0-50
		WARSAW FORMATION	Shale	0-90
		KEOKUK-BURLINGTON FMS.	Cherty limestone	200-25
	KINDERHOOKIAN		Shale	200-24
DEVONIAN			Limestone	0-50
SILURIAN			Dolomite	50-25
ORDOVICIAN	CINCINNATIAN	MAQUOKETA GROUP	Shale, dolomite	170-20
	CHAMPLAINIAN	GALENA-PLATTEVILLE GPS.	Dolomite	290-34
		GLENWOOD-ST. PETER FMS.	Sandstone	170-25
OLDER ORDOVICIAN, CAMBRIAN, & PRECAMBRIAN ROCKS				

Fig. 7. Unconsolidated deposits and bedrock formations of the Havana region.

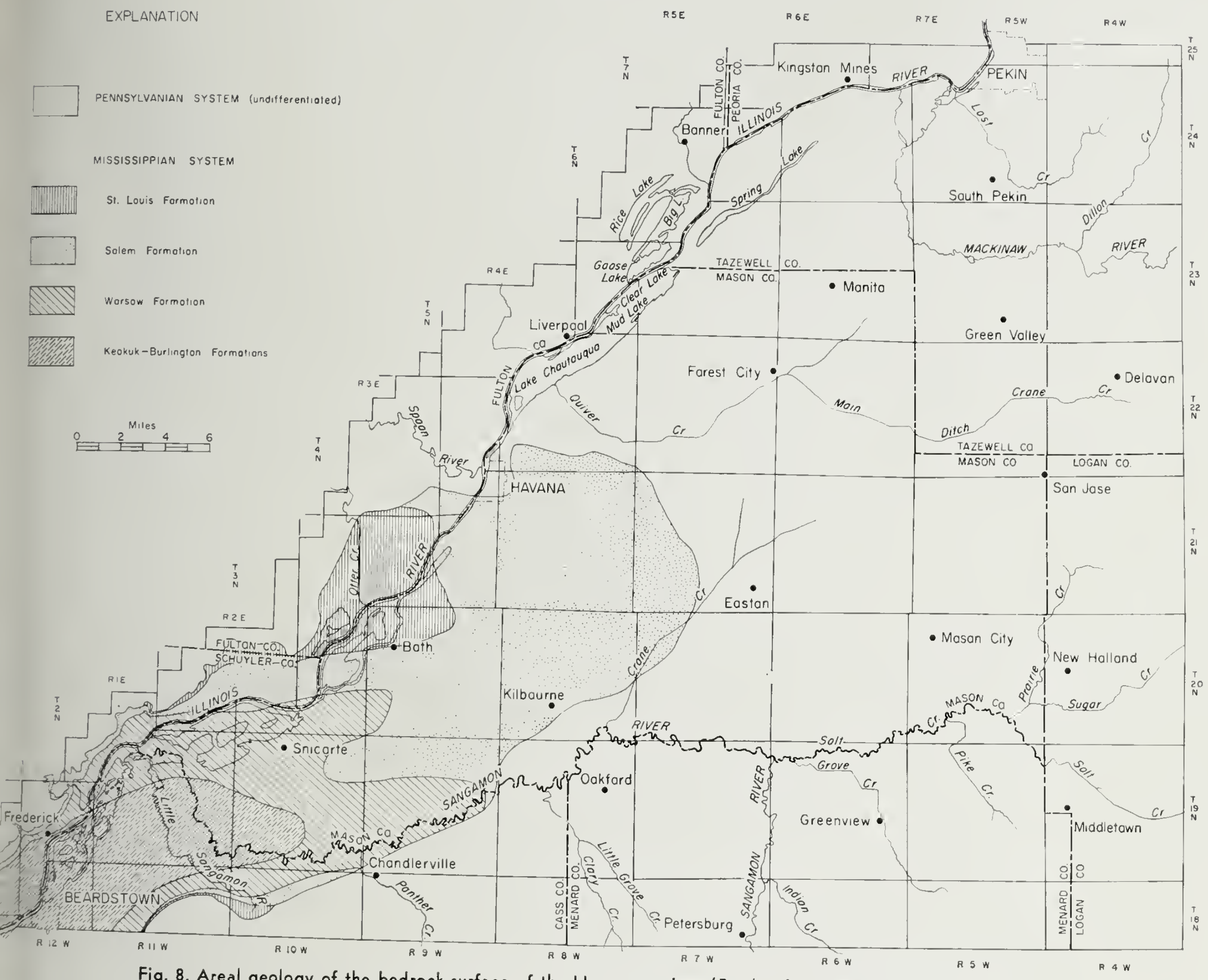


Fig. 8. Areal geology of the bedrock surface of the Havana region. (Partly after Wanless, 1957, pl. 5.)

ore than 100 feet of unconsolidated deposits cover
edrock in most of the Havana region; however, bed-
crops out in the steep bluffs west of the Illinois
and east of Pekin and in the bluff of the Sangamon
east of Beardstown. The sequence and descrip-
of both the unconsolidated deposits and bedrock
hown in figure 7.

re and Water-Yielding Properties of the Bedrock

bedrock formations dip generally to the southeast
average rate of 15 to 20 feet per mile. Locally the
are warped into minor folds. Northwest of Manito,
ch upfold has been explored for oil and, later, for
ge of natural gas.

youngest bedrock formations in the region are of
ylvanian age. They occur directly below the drift
zewell County and much of Mason County. Erosion
Illinois River Valley south of Havana has reached,
sively, the St. Louis, Salem, Warsaw, and Keokuk-
ngton Formations (fig. 8).

Pennsylvanian rocks crop out extensively in the west bluffs and tributaries of the Illinois River and are exposed in many strip mines in Fulton, Schuyler, and Peoria Counties. The exposures have been described in detail by Wanless (1957). They consist mainly of shale, but include at least five minable coals and several beds of sandstone and limestone. In general, the Pennsylvanian rocks are relatively unfavorable as a source of ground water, although fractured zones or beds of sandstone locally yield up to 10 gallons per minute (gpm) to wells.

The Mississippian formations are mainly limestone and shale, with some dolomite and sandstone. In recent test drilling for gas storage northwest of Manito, water-yielding zones were encountered throughout the interval of the Keokuk-Burlington Limestone between depths of about 400 and 600 feet. Udden (1908, p. 330–331) also reported water-yielding zones in this limestone in Peoria. The other Mississippian rocks rarely yield appreciable quantities of water. Wells tapping Mississippian rocks in this area seldom have yields exceeding 20 gpm.

Water-yielding crevices are fairly abundant in the Devonian and Silurian rocks, but water in these rocks is generally reported as salty or sulfurous. An analysis of water from Devonian and Silurian rocks at a depth of 1100 to 1136 feet in well MSN 21N5W-19.1h shows 7772 parts per million (ppm) total dissolved solids (tds) and 4260 ppm chlorides (Meents et al., 1952, p. 35). The high mineralization of ground water may be a result of poor circulation of fresher waters through the rocks, resulting from limited lateral openings, and containment by relatively impermeable shale formations below and above.

The Galena-Platteville Dolomite and Glenwood–St. Peter Sandstone of Ordovician age have yielded ground water to most deep wells in the region. Although water in the Galena-Platteville and Glenwood–St. Peter rocks is less highly mineralized than that in the Devonian and Silurian rocks because of better circulation of fresher water through the permeable sandstone, it is still too highly mineralized for most domestic uses. Water occurs in the Galena-Platteville Dolomite in solution openings along fractures and bedding planes. It occurs in the Glenwood–St. Peter Sandstone in the pore spaces between grains. The water is under artesian pressure, and flowing wells usually result where land surface is below an elevation of about 535 feet. In well MSN 22N6W-19.7e at elevation 495 feet, water began flowing at the surface when drilling reached a depth of 1295 feet, or 6 feet into the top of the Galena-Platteville Dolomite. An estimated flow of 5000 barrels a day (138 gpm) of water was reported for an oil test well (MSN 22N8W-31.8e, elevation 472 feet) that penetrated the Galena-Platteville Dolomite from 1140 to 1435 and the Glenwood–St. Peter Sandstone from 1435 to 1442 feet.

Most oil tests in the region have gone no deeper than the Glenwood–St. Peter Sandstone. Below the Glenwood–St. Peter lies some 3000 feet of older sedimentary rocks of Ordovician and Cambrian age. The water in these rocks probably is highly mineralized. The sedimentary rocks overlie still older Precambrian crystalline basement rocks, mainly granites.

Bedrock Topography

The Havana region is essentially that described by Horberg (1950, p. 25, 36) as the Havana Lowland, a subdivision of the buried Pennsylvanian Lowland. Following Horberg's interpretation, figure 9 shows that the broad Havana Lowland and its extensions upstream developed at the junction of several important drainage lines and just above the point where massive Mississippian limestones cross the valley at Beardstown. The combined discharge of large streams in the Mahomet and Mackinaw bedrock valleys and the narrow Peoria-Pekin channel accomplished much of the excavation of the wide bedrock lowland in the relatively weak Pennsylvanian rocks.

The configuration of the bedrock surface (fig. 10) and the nature of the overlying and underlying rocks are in-

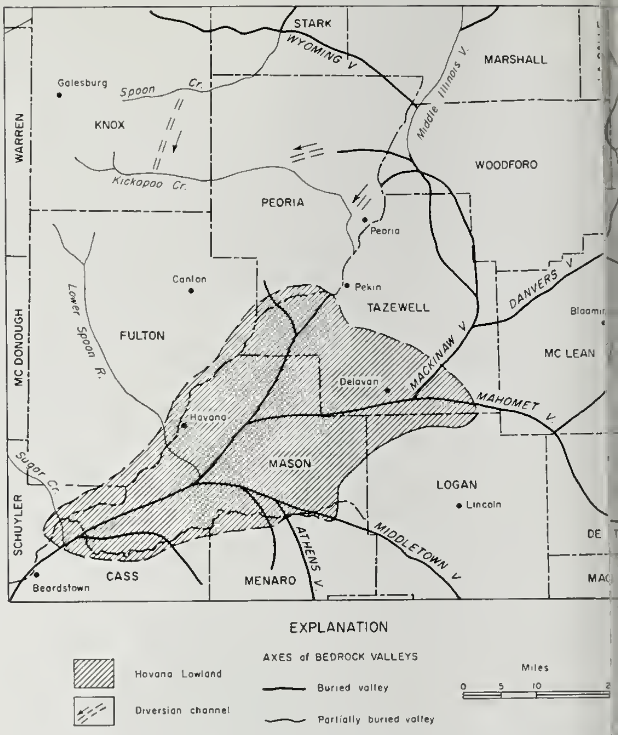


Fig. 9. Bedrock valleys of west-central Illinois and location
Havana Lowland. (Modified from Horberg, 1950, pl. 2.)

terpreted from logs of about 300 wells and borin
which 117 are records based on studies of drill cut
Seventy-eight of the logs are from oil or coal tests
penetrated the bedrock to a considerable depth.
stations, bedrock surface elevations were calculated
seismic data. (See Addendum, p. 54.)

The Havana Lowland (figs. 9, 10, and 11) consi
gently rolling to fairly flat bedrock benches notch
channels. The floor of the lowland is generally bel
elevation of 400 feet, whereas the adjoining bedroc
land has some elevations above 500 feet (fig. 10).
southern and western boundaries of the lowland a
eastern boundary north of South Pekin are esse
steep walls, as shown by the proximity of the 400-
500-foot elevation contours. The eastern boundar
slopes that rise gradually above the broad bedrock
ley that passes beneath Delavan.

The flat to rolling benches are the most wides
erosion surfaces in the Havana Lowland. The be
have a gradual rise to the north, from an elevati
about 340 feet at Beardstown to slightly below 40
east of Manito. The benches also widen northwar
Beardstown a narrow bench is developed on the resi
Keokuk-Burlington rocks (fig. 11, A—A′), where
the north, benches developed on the softer roc
Pennsylvanian age (fig. 11, B—B′) are wider. Ho
(1950, p. 96) considered the benches represented a
spread erosion level (Havana Strath) that was br
about by lateral cutting upstream from Beards
where the river crossed the Keokuk-Burlington ro

Channels are cut from 50 to 80 feet below the level the lowland benches. The main channel, carved by mbined drainage of the Mahomet and Mackinaw bedck valleys, passes southwestward beneath Delavan and eardstown, with tributary channels that approximately nderlie Middletown, Greenview, Petersburg, Chandlerlle, Spoon River, Glasford, and Pekin. The floor of the ain channel has an elevation below 320 feet and is exvated in Pennsylvanian rocks to a point between Hana and Easton and in Mississippian rocks southward igs. 8 and 11). Horberg (1950, p. 96–99) referred the annels to a "deep valley" stage of erosion that ocrred subsequent to the development of the Havana rath.

In cross sections the channels appear to be narrow and shaped in some reaches and fairly broad in others (fig. A—A′ and B—B′). It is likely that the actual conurations would prove to be less anomalous and closely lated to lithology and structure if abundant well control were available. Additional well control might also change the interpretation of the elevation of the floor of the main channel. Horberg's map of bedrock topography (1950, pl. I) showed a deep channel in the Havana region with elevation below 300 feet, whereas this study suggests that the main channel floor is somewhat higher (fig. 10). Our report also departs from Horberg's map in placing the main deep channel in a more northerly position and giving a more westerly lower course for the Middletown Valley.

The bedrock channels are important from the standpoint of ground water because they contain the thickest sand and gravel deposits (fig. 11). They are commonly overlain by deposits 50 to 75 feet thicker than those on adjoining benches. The benches are overlain by substantial deposits of sand and gravel in some areas, but in others they are high enough to approach the level of present drainage (fig. 11, B—B′).

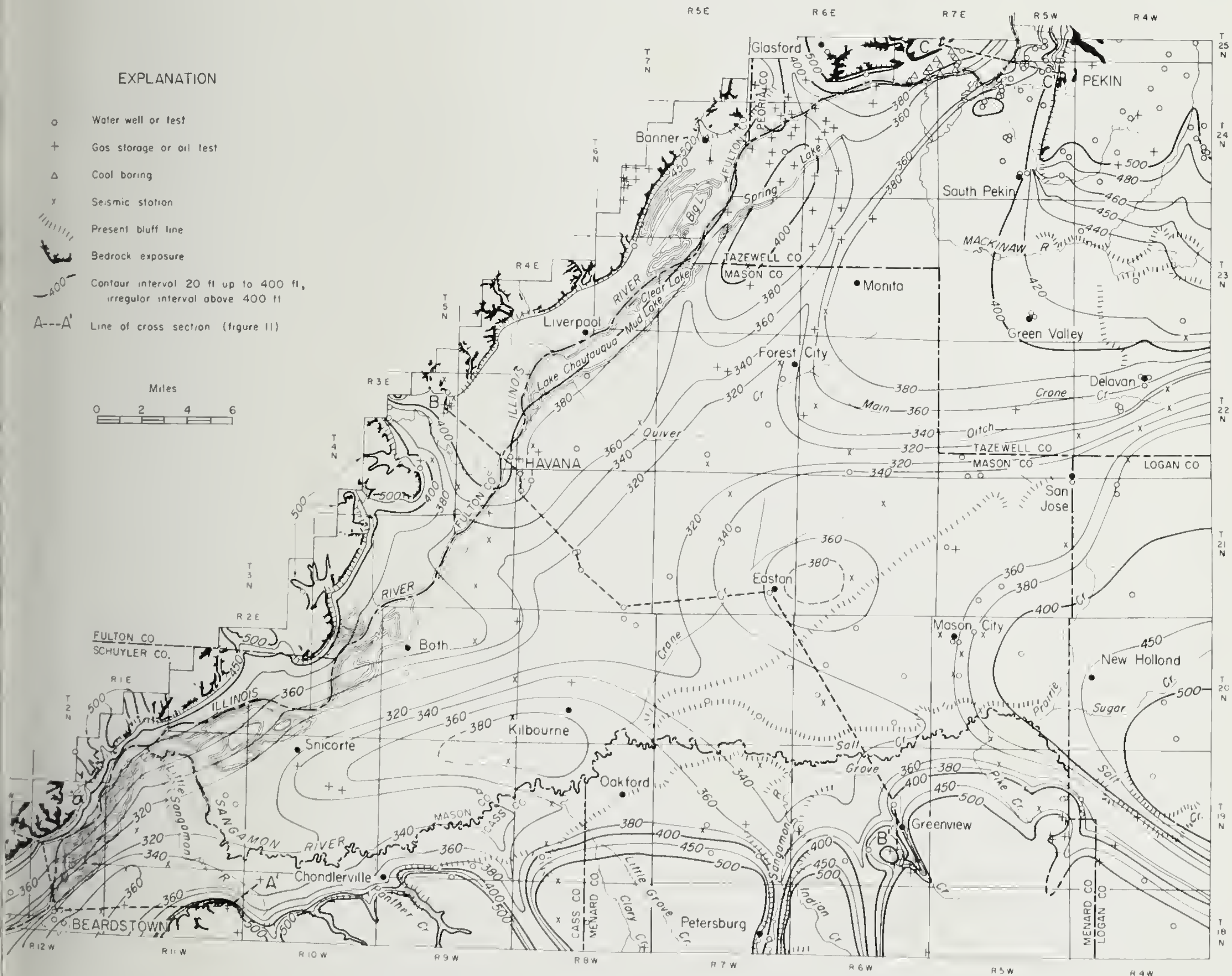


Fig. 10. Bedrock topography of the Havana region. Cross sections are shown in figure 11. (See Addendum, p. 54).

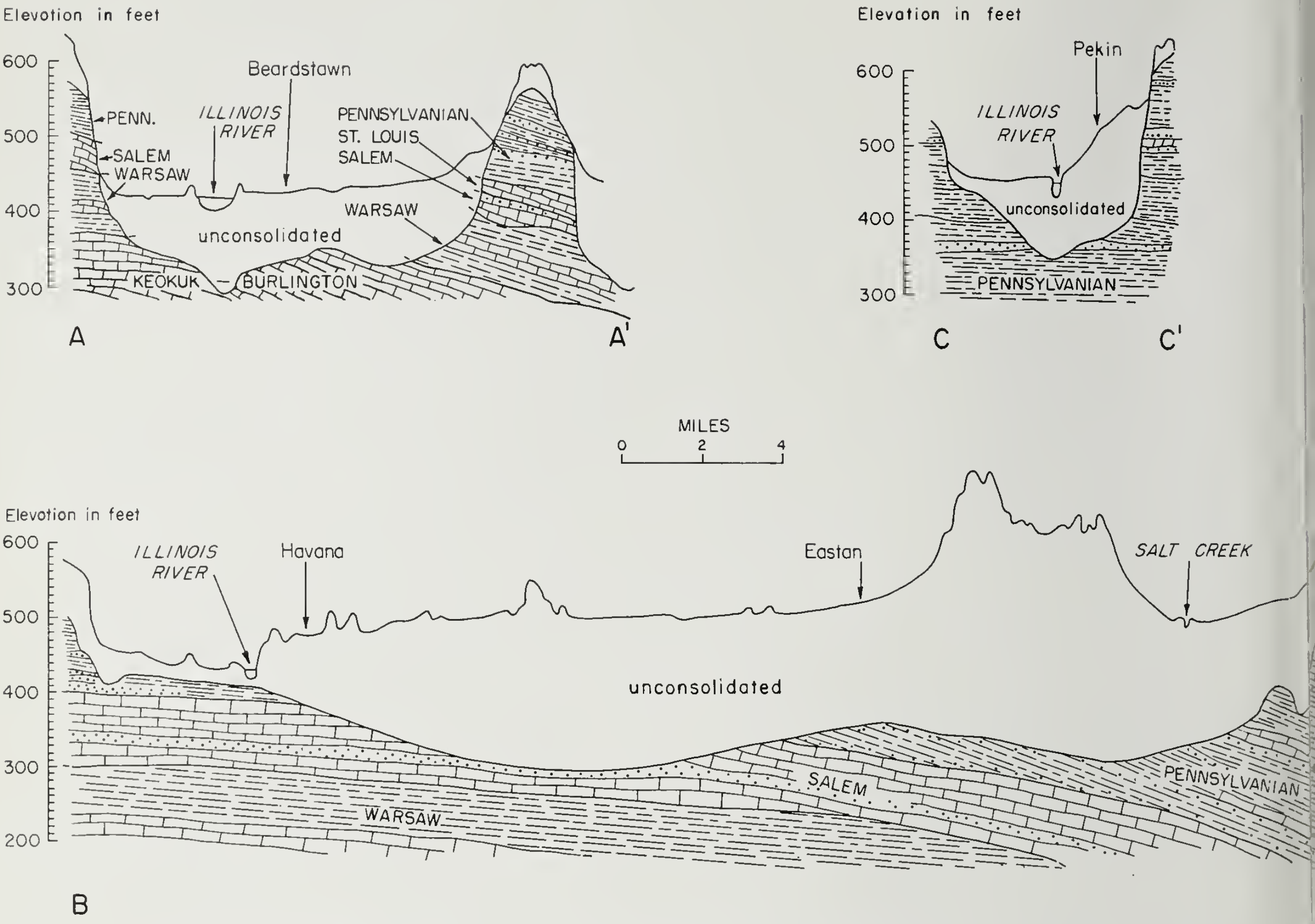


Fig. 11. Cross sections of the bedrock in the Havana region. Lines of cross section are shown in figure 10.

Except in the narrow valley north of Pekin and the valley south of Beardstown, the Illinois River at present occupies a course along a bedrock bench and is well to the west of the deep bedrock channel. Consequently valley sediments are much thinner along the river than in most of the Havana region. Between Havana and Kingston Mines where the bedrock bench is above elevation 400 feet (fig. 11, B—B′), it is likely that in times of scour the Illinois River reaches bedrock. On the other hand, the bedrock surface is relatively deep beneath the lower courses of the Sangamon River and Salt Creek.

Unconsolidated Deposits

Distribution and thickness

Sand and gravel constitute the bulk of the unconsolidated deposits below the Wisconsinan terraces (figs. 12 and 13). However, below the Illinoian and Wisconsinan drift uplands, such as those at Mason City and Delavan (fig. 13), the sands and gravels occur just above bedrock and are overlain by about 100 feet of finer grained, wind-blown, ice-laid, and mixed deposits.

The basal sand and gravel deposits are fairly distinct lithologically and have been named Sankoty Sand (Horberg, 1950, p. 51-52; Horberg, Suter, and La 1950, p. 34-36). Beneath the upland the top of Sankoty is between elevations of 450 and 500 feet; average elevation is about 490 feet. The Sankoty t and terminates east of Mason City and north of Dela as the bedrock surface rises (fig. 13), but the dep continue to the east up the Mackinaw-Mahomet bed valley beneath Delavan and westward beneath the races where they underlie Wisconsinan glacial sa and gravels. They also are present in the Peoria where they overlie the bedrock in the deeper valleys in turn are overlain by Illinoian and older drifts. posits in similar stratigraphic position in the Maho Valley were named the Mahomet Sand (Horberg, 1 p. 18-20). The Mahomet Sand probably is present the Havana Lowland, but because it is less distinc than (and is no doubt mixed with) the Sankoty S it has not been differentiated.

The unconsolidated deposits of the Havana reg range from a few feet to more than 400 feet thick (14). The thickest deposits occur west of Mason (where a tract of high kames and dune sand is underl by the deep Middletown and Athens bedrock vall (figs. 9, 10, and 13, B—C). Thin deposits (less t 50 feet) occur along and west of the Illinois Ri roughout the broad tract of terraces from the river t to the Illinoian and Wisconsinan drift uplands :. 12), the sand and gravel deposits are from 100 to feet thick. The deposits are commonly from 125 to feet thick above the broad bedrock benches of the ion, whereas they exceed 200 feet in some of the rock channels (fig. 13).

'he lines showing the thickness of the unconsolidated osits in figure 14 reflect both bedrock topography present land surface features. For example, the er-like contours west of San Jose, north of Forest r, and between Bath and Kilbourne show the thicken- of the drift in deep bedrock channels. The crenu- d or closed contours west of Mason City outline some the high sand hills. The 200-foot thickness line ning northeastward between Kilbourne and San marks the rise of the Illinoian drift upland.

tory

lanation of the broad Havana Lowland was complete r to the advance of the Kansan glacier, as the presence of pre-Illinoian (probably Kansan) till in bedrock valleys to the east suggests, and may possibly have been complete before Pleistocene time (Horberg, 1950, p. 96-99; Wanless, 1957, p. 127-128). The deeper channels incised in the Havana Strath suggest that erosion proceeded in two stages.

Glacial ice advanced into the area adjacent to the Havana Lowland during both the Nebraskan and Kansan Stages (Wanless, 1957, p. 128-133; Horberg, 1953, p. 15-23). Within the lowland itself no ice-laid deposits assignable to these stages have been recognized, but the Sankoty and Mahomet Sands are now considered by the Illinois Geological Survey to be Kansan outwash deposits. The sands were deposited to an elevation of almost 500 feet, or about 200 feet above the bedrock floors. The Sankoty Sand was derived from sandstones and crystalline rocks in Wisconsin and Minnesota and was carried southward through the Middle Illinois and Mackinaw Valleys into the Havana Lowland. The Mahomet Sand appears to have been derived from glacial deposits (Manos, 1961). Later, melting of the Kansan ice left the Mackinaw Valley and much of the Mahomet

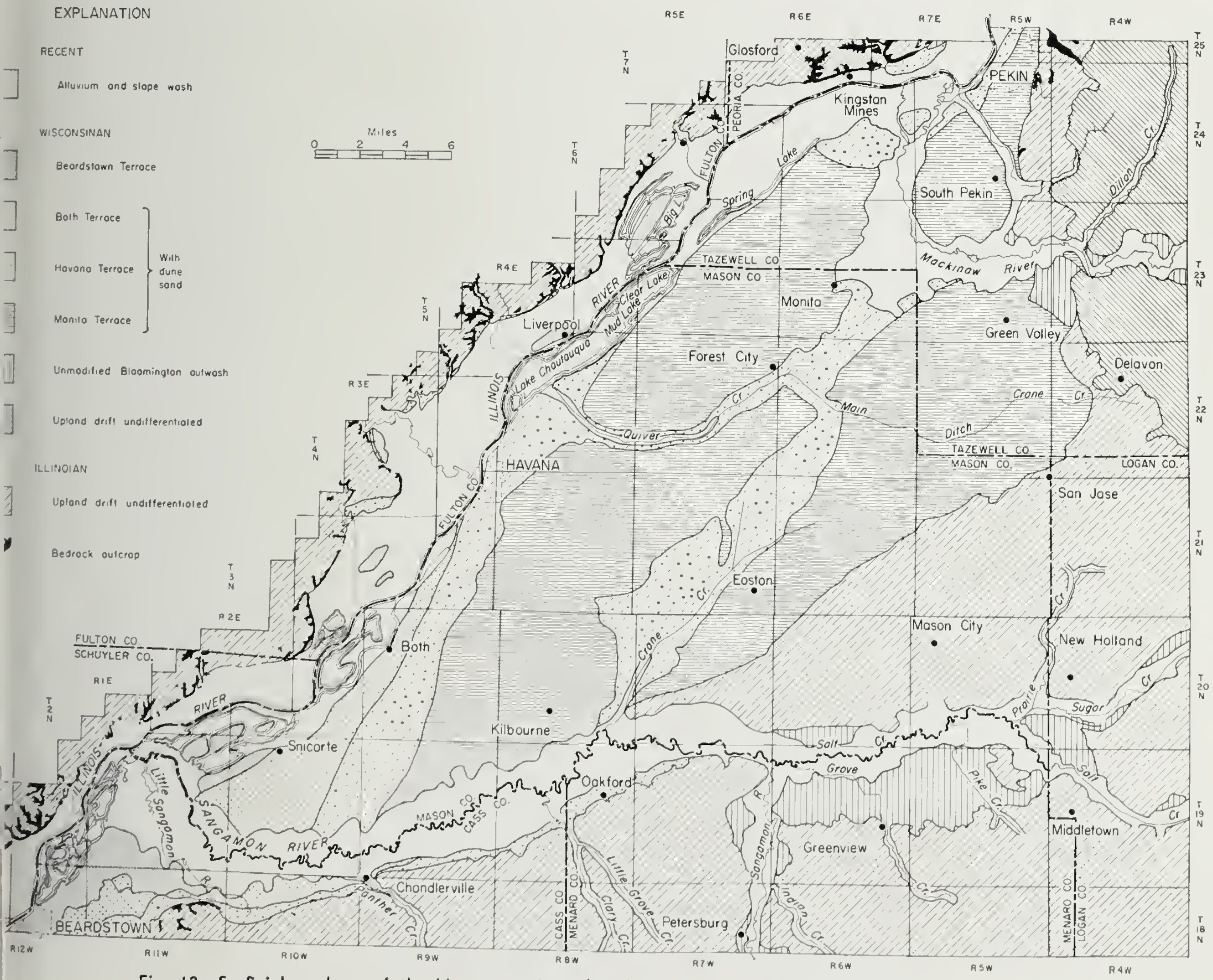


Fig. 12. Surficial geology of the Havana region. (Modified from Wanless, 1957, pls. 1-3, fig. 59.)

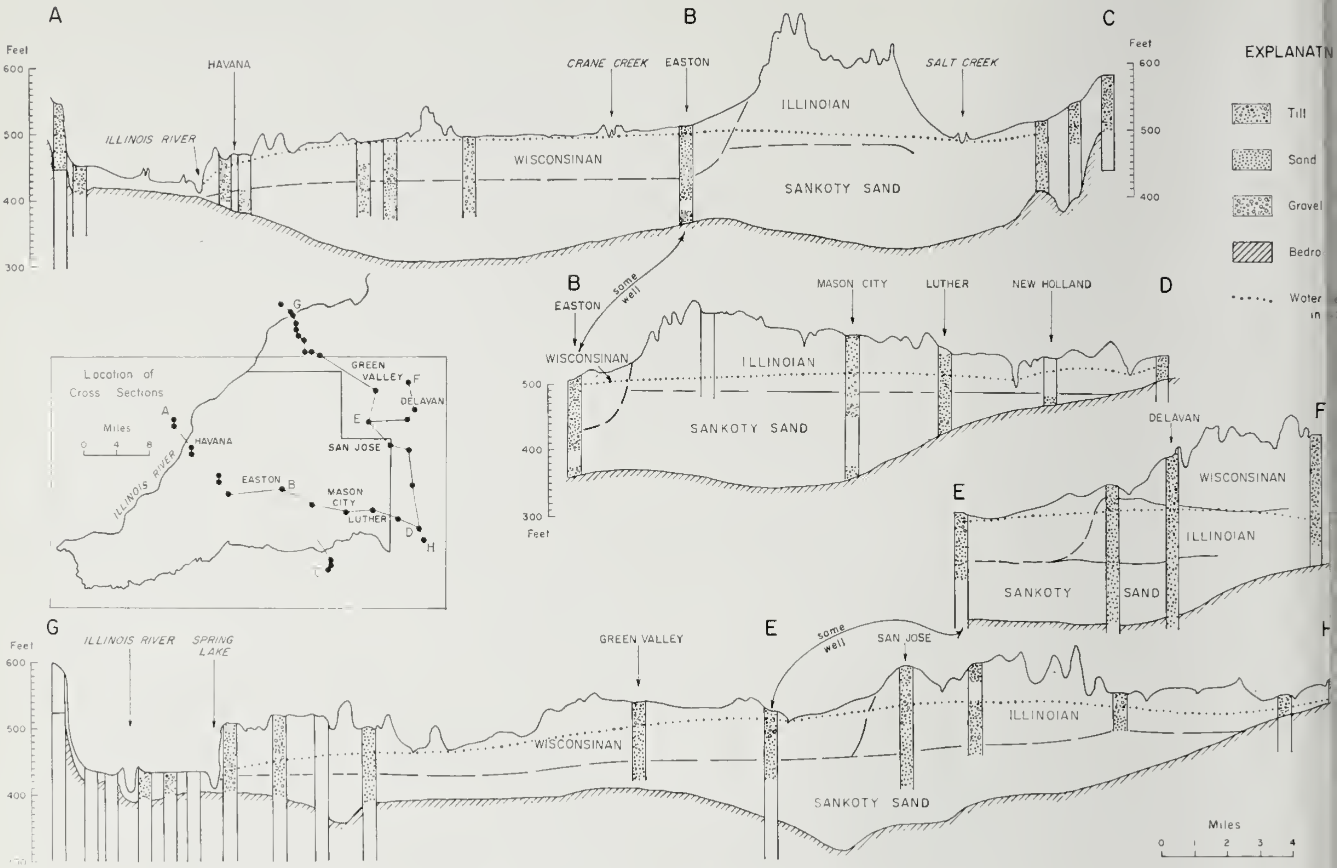


Fig. 13. Cross sections of the unconsolidated deposits of the Havana region, with profiles of the water table, 1960.

Valley filled with drift, and the Peoria-Pekin channel probably began carrying the main drainage from the north.

The Illinoian glacier advanced from the northeast approximately as far south as Harrisburg and Murphysboro in Illinois and as far west as southeastern Iowa. It built low, discontinuous moraines, one of which (Buffalo Hart) forms the hilly ridge in southeastern Mason County and continues south across the east end of Menard County. To the east and southeast in Logan and Sangamon Counties the Buffalo Hart Moraine is associated with a complex of sandy crevasse fillings and moulin kames. During Illinoian time abundant meltwater was channeled into the Havana region, resulting in the deposition of sandy drift. After the Illinoian glacier melted, the surficial drift was weathered and extensive erosion occurred along the Middle Illinois Valley and the Peoria-Pekin channel.

The beginning of Wisconsinan glaciation was marked by a spread of outwash down the Illinois River Valley. Winds blew silt from the outwash flats during dry periods and deposited it on the adjoining uplands as loess. Wisconsinan glaciers later advanced to the vicinity of Delavan, Pekin, and Peoria and built a series of end moraines that rise above the loess-blanketed Illinoian drift plain. During the building of one of these moraines, the Bloomington, meltwater from the ice built a thick valley train or outwash fan of sand and gravel
down the Illinois Valley past Pekin to south of Be
town. The surface of the outwash fan (unmo
Bloomington outwash, fig. 12) sloped from an elev
of about 640 feet near Peoria to about 485 feet
Beardstown (fig. 15; Wanless, 1957, p. 175). The
of the fan cut well into the much older Sankoty dep
When the ice retreated from the Bloomington end
aine a lake was formed in the Illinois River Valley
of Peoria. It discharged through a narrow channel
the west valley wall, a course the river still follows

Subsequently, when the Wisconsinan glacier was
ing in northeastern Illinois, south-central Michigan,
northern Indiana, a great flood of meltwater
Kankakee Flood) poured down the Illinois Valley
ing channels in the Bloomington outwash fan and b
ing sand bars. As the volume of meltwater subsid
was confined within the Illinois, Mackinaw–Q
Creek, and Crane Creek Valleys. The Manito and
vana Terraces (fig. 12) record levels of erosion o
original Bloomington outwash fan surface, whic
preserved in a few protected places along tribu
valleys. During low-water stages of the Kankakee F
the sands and silts exposed as bars were rework
the wind into dune complexes.

Later, during the melting of the Wisconsinan
further erosion along the Illinois River developed
Bath Terrace. The Beardstown Terrace was for

ter a stage of deeper erosion, along the river by sand d gravel deposited when the flow of meltwater diminıed.

thology and water-bearing properties

The unconsolidated deposits, which in general can be bdivided into those of the bedrock valley or lowland ɐas and those of the adjoining bedrock uplands, occur units that have considerably different properties in ation to the occurrence and movement of ground ter. Sands and gravels of the valley areas are the in aquifer of the region, whereas the finer grained land deposits are significant chiefly for their control the percolation of rainfall to the water table and to ply buried sand and gravel deposits.

The individual units of unconsolidated deposits (fig. are discussed in detail in the following sections.

ıkoty Sand

The Sankoty Sand is typically pinkish gray, medium-coarse-grained sand. About 75 percent of the grains are composed of quartz, 10 to 15 percent of feldspar, and 10 to 20 percent of crystalline and sedimentary rocks. More than 75 percent of the quartz grains are clear and untinted, the majority subrounded to rounded. From 10 to 20 percent of the quartz grains are pink, and many have flecks of reddish stain in tiny pits. The abundance of pink-tinted quartz and potash feldspar grains gives the Sankoty the pink cast that helps distinguish it from overlying deposits.

Texturally, the Sankoty Sand ranges from fine to very coarse sand with granule gravel, although beds of clean, well sorted, medium to coarse sand are most common. Gravel beds are somewhat more abundant in the narrower parts of the bedrock valley north of Manito and in the area south of Beardstown than in the wide reach east of Havana. In general, however, the Sankoty Sand is finer than overlying Wisconsinan outwash. For example, sieve analyses (fig. 16) of samples from well MSN 21N8W-6.8g2 (Havana City Well 4) show coarser Wisconsinan deposits to a depth of 50 feet and finer, well sorted Sankoty Sand below.

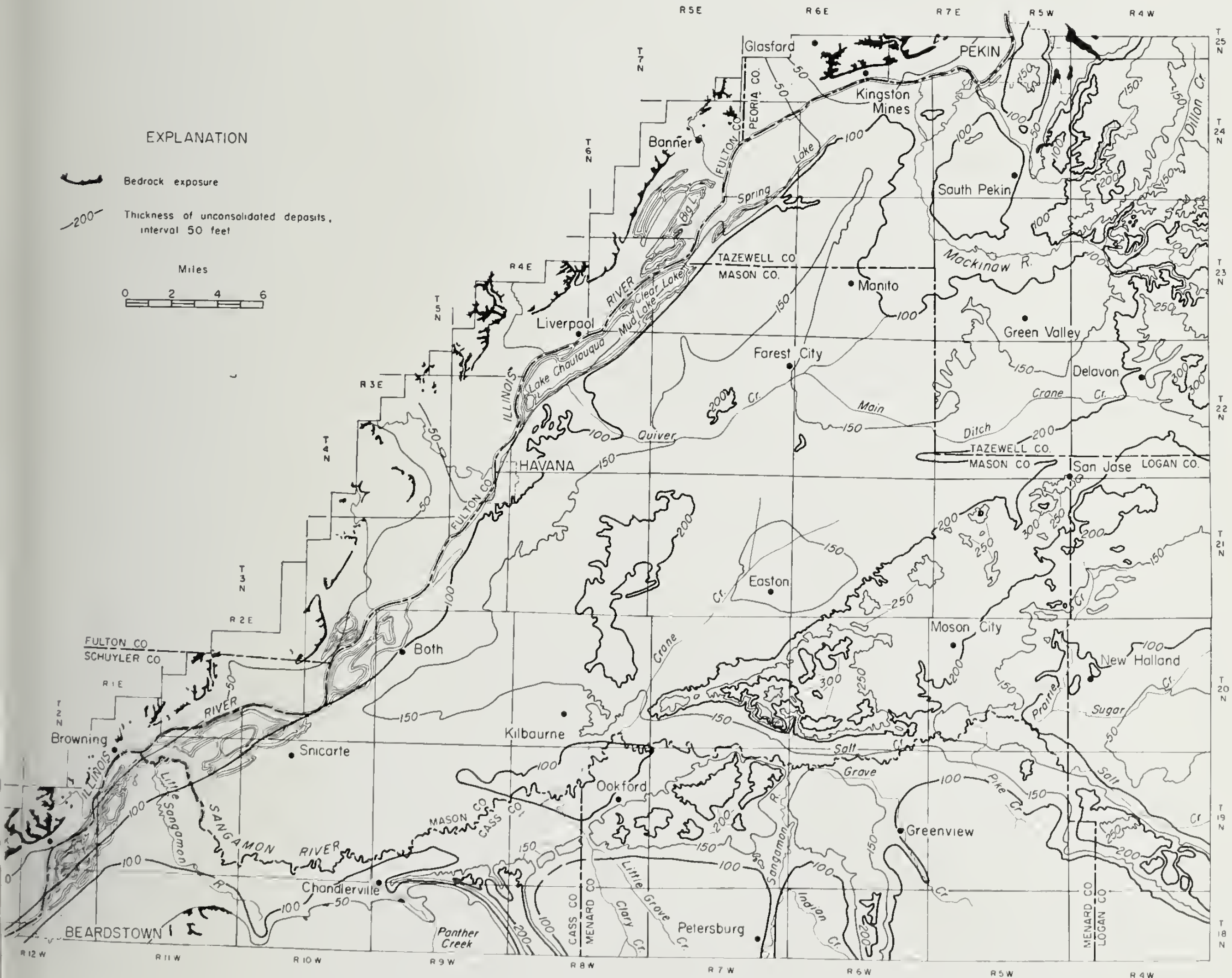


Fig. 14. Thickness of the unconsolidated deposits in the Havana region.

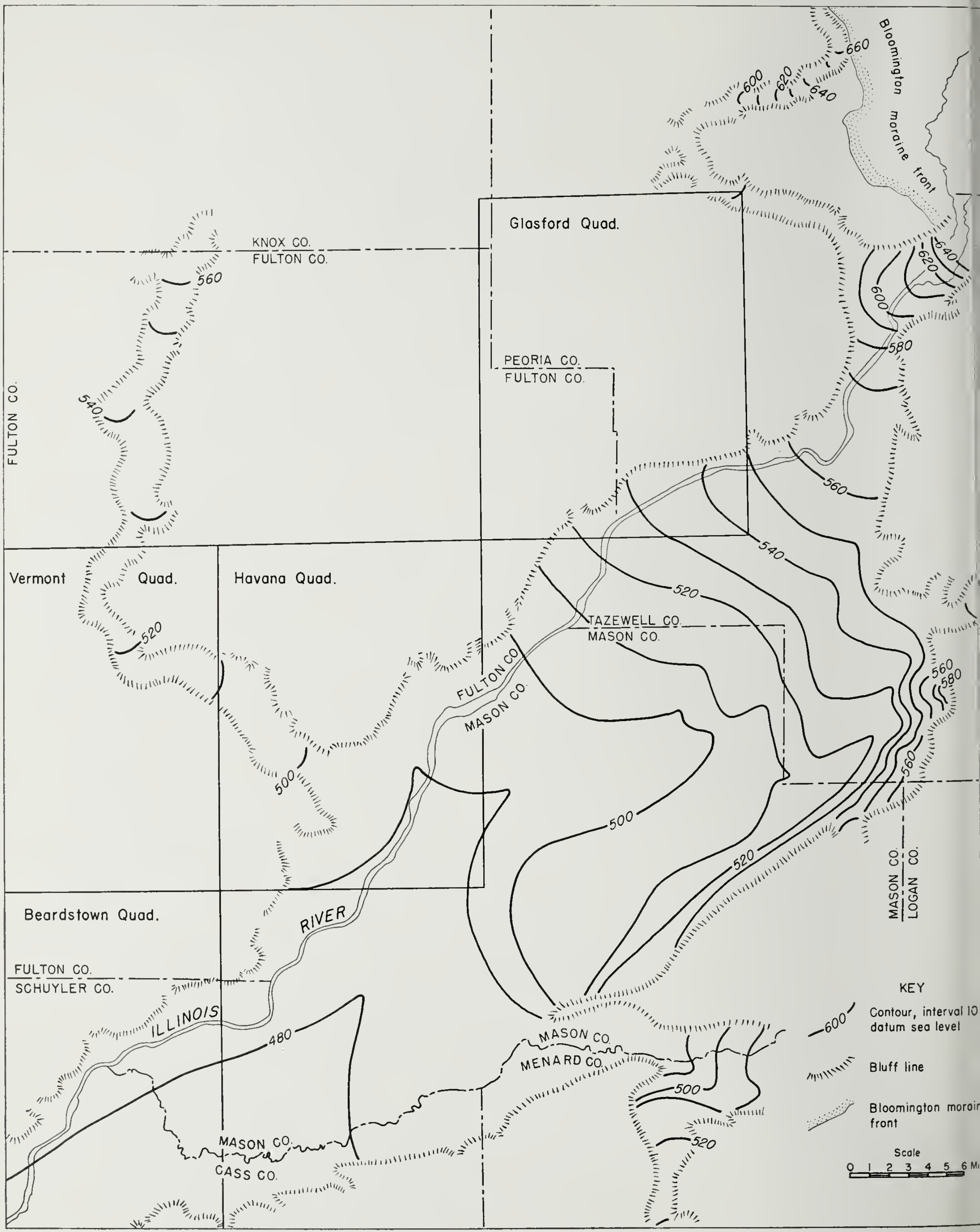


Fig. 15. Contour map showing the original form of the Bloomington valley train (Wanless, 1957, fig. 58).

The coarser fractions of the Sankoty Sand (coarser an 4 millimeters) are composed dominantly of dolomite 6 to 56 percent noted in random counts), chert (9 to percent), limestone (8 to 13 percent) and fine-grained, rk, igneous rocks (3 to 13 percent). Dolomite pebbles significantly more common than in the shallower isconsinan outwash.

The Sankoty Sand overlies the bedrock throughout ich of the Havana region and can be identified in ll cuttings, except in some localities where it is xed with other deposits or has been eroded. Its thick- s varies greatly because of the irregular surface on ich it was deposited and because of erosion of its per surface. It is probably missing beneath the sent valley of the Illinois River (fig. 13). It may ain a maximum thickness of some 175 feet where the p bedrock channel underlies the Illinoian and Wis- sinan upland, but generally it is less than 125 feet k. The elevation of the top of the Sankoty Sand s from Havana eastward toward Mason City and avan and northward toward Pekin, averaging about feet at Havana, 445 at Forest City, 450 at Delavan, at Mason City, and 440 at South Pekin.

Vhere the Sankoty Sand is recognizable below the sconsinan terraces, it appears to be overlain directly Wisconsinan outwash. Illinoian deposits, if present, not be recognized. The sample study log of well MSN 21N6W-28.1g on the Manito Terrace between Havana and Kilbourne illustrates the sequence of Wisconsinan outwash above Sankoty deposits.

	Thickness *(ft)*	Depth to base *(ft)*
Pleistocene Series		
No samples	18	18
Wisconsinan Stage (Bloomington outwash)		
Sand, fine to medium; yellowish brown subangular grains; ferruginous staining; abundant yellowish quartz grains; some brown silt	8	26
Sand, medium, as above; some granule gravel	10	36
Silt, brown, calcareous	2	38
Sand, medium; yellowish brown subangular grains	4	42
Sand, medium to coarse with granule gravel, yellowish brown; granules of dolomite, quartz, and granite	12	54
Sand, fine to coarse, some very coarse, yellowish brown; abundant grains of yellowish quartz and feldspar	12	66
Kansan Stage		
Sankoty Sand		
Sand, medium to coarse, pinkish gray; subangular to rounded grains; abundant pink and pink-stained quartz grains; some granule gravel and fine sand beds	22	88

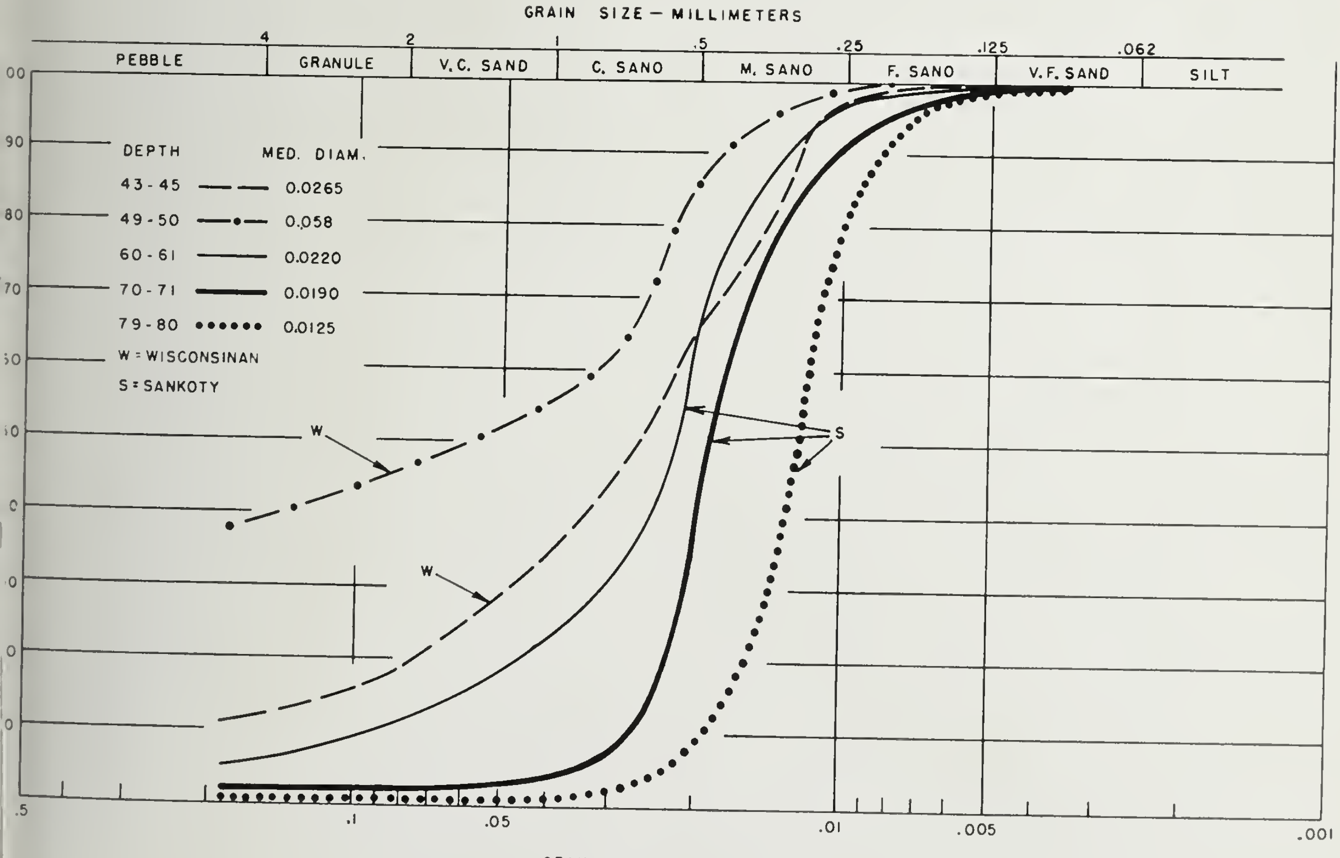


Fig. 16. Sieve analyses of samples from well MSN 21N8W-6.8g2.

Sand, fine to very coarse, pinkish gray; abundant pink grains; some granules of dolomite, quartz, feldspar, and igneous rock	10	98
Sand, fine to medium, reddish brown, subangular; abundant pink grains; many grains with pink clay skins	8	106
Sand, medium to very coarse, pinkish gray; pink grains; granules of chert dolomite and dark igneous rock	12	118
Gravel, granule, with very coarse sand; granules of dolomite, granite, sandstone, felsite, and dark igneous rock	4	122 (total depth)

The Sankoty Sand and the overlying Wisconsinan outwash constitute the main aquifer of the Havana region. They form a fairly homogeneous unit that extends from near land surface to bedrock in the broad Wisconsinan terrace area. Most wells on the terraces that are 100 or more feet deep penetrate at least the upper part of the Sankoty Sand (fig. 13). The Sankoty Sand also extends eastward beneath the Illinoian upland, where it is overlain by heterogeneous Illinoian deposits. In the area of the broad bedrock valley east of Delavan, the Sankoty and the related Mahomet Sand are overlain by both Illinoian and Wisconsinan drift.

Composed of well sorted, generally clean sand and gravel, the Sankoty Sand is a highly permeable reservoir with considerable areal extent. Recharge to the Sankoty Sand is most rapid where it is overlain by the Wisconsinan outwash, because the outwash itself is permeable and in much of the area is covered by dune sands that lack integrated drainage lines, which facilitates infiltration of rainfall. Recharge conditions are less favorable beneath the Illinoian uplands because layers of till overlie the Sankoty. Recharge to the Sankoty is poorest beneath the Wisconsinan drift uplands where it is overlain by both Illinoian and Wisconsinan tills.

Other Pre-Illinoian Deposits

Occurrences of pre-Illinoian deposits west of the Illinois River were described by Wanless (1957, p. 128-133) and those east of the river by Horberg (1953, p. 20-25). They are primarily remnants of weathered tills found at low elevations in outcrops and indicated in wells. With the exception of the Sankoty Sand, pre-Illinoian deposits are not recognized in the Havana region and are not important from the standpoint of ground-water occurrence.

Illinoian Deposits

Illinoian drift in the upland around Mason City, south of San Jose, and north of New Holland (fig. 12) is mantled by loess and is well exposed in only a few places along the north bluff of Salt Creek and the Sangamon River, where it is dominantly sand and gravel and is locally associated with dense, dark lo
to reddish brown, very sandy, pebbly till. A grav
in the north bluff of the Sangamon River in NE¼ E
NE¼ sec. 36, T. 20 N., R. 7 W., Mason County, h
following section:

	Thickn *(ft)*
Pleistocene Series	
Wisconsinan Stage	
Peoria Loess	
Silt, reddish at base, becoming tan above, slightly calcareous	10
Illinoian Stage	
Till, orange to reddish brown, dense, sandy, noncalcareous; abundant pebbles	4 to 8
Sand and gravel, gray to tan; cobbles up to 8″ in diameter; beds dip back into bluff to north (elevation of base of exposure, 595′)	40 expo

Essentially the same sequence of sand and g
dense till, and reddish and tan silts is repeate
several exposures in the bluff for the next 10 miles
The silts are considered to be Wisconsinan dep
whereas the till and associated sand and gravel de
are believed to be Illinoian.

A complex array of reddish to pinkish coarse g
with boulders, bedded sands, and silts is expose
roadcuts across the narrow, rough upland east of C
Creek and north of the Sangamon River. The l
coarse deposits are considered Illinoian, and the u
pink silts and sands are considered Wisconsinan.

A gravel pit a mile west of San Jose (NE¼ N
NE¼ sec. 2, T. 21 N., R. 5 W., Mason County) s
10 feet of well bedded sand and gravel dipping n
ward, with boulder beds in which some indivi
boulders are as much as 1½ feet in diameter. Br
laminated sand and silt overlie the sand and gr
and are in turn overlain by crudely layered, peb
clayey colluvium and additional sand and gravel.
deposits are all part of the Illinoian kame comple

Well records showing subsurface details of the
noian deposits in the vicinity of Mason City and
Jose are scarce. Probably some Illinoian till and o
fine-grained sediments are present in addition to s
and gravel.

A drillers log of well MSN 20N5W-17.8c, 2 m
north of Mason City, recorded the following seque

	Thickness *(ft)*	De to (
Soil	6	
Yellow clay	33	
Red sand	12	
Blue sand	32	
Quicksand	21	1
Coarse gravel	6	1

Samples from well MSN 20N5W-7g2 at Mason City ow the following sequence:

	Thickness (ft)	Depth to base (ft)
istocene Series		
Visconsinan Stage		
Soil	5	5
Sand, fine (wind-blown), brown, noncalcareous	35	40
Silt, brown, noncalcareous	5	45
llinoian Stage		
Till (?), brown, silty	5	50
Sand, medium to coarse	5	55
Sand, very coarse; granule gravel; very dirty (till?)	10	65
Till, yellowish brown, calcareous	20	85
Sand, fine to medium, calcareous	5	90
ansan Stage		
No samples	105	195
Sankoty Sand		
Sand, very fine to fine, brown, abundant pink grains	4	199
Sand, medium to very coarse; granule gravel	21	220 (total depth)

hese logs suggest that Illinoian till is present in the th range of 50 to 85 feet, with loess and wind-blown d above and mainly sand and gravel below. Scarcity subsurface information prevents the projection of sequence to the west with certainty. A few well ords from northwestern Logan County southeast of Jose indicate that the Illinoian deposits are com- d of finer grained materials, logged as "clay," rdpan," or "drift," rather than as "sand and vel."

linoian drift in Tazewell County east of Pekin is inantly compact dark gray till that contains some- t more sand and silt than nearby or overlying Wis- inan tills. The Sangamon weathered zone is com- ly recognized on top of the Illinoian drift in out- s and is indicated in drillers records by such terms old soil," "peat," "black muck," or "dark clay." linoian deposits west of the Illinois River are as- ed to the Liman, Jacksonville, and Buffalo Hart stages. These Illinoian tills are lithologically similar unless, 1957) and are differentiated on the basis of position in and behind end moraines. The till ages 25 to 35 feet thick, is light gray where un- hered, locally contains large blocks (6 to 16 feet in eter) of sedimentary and igneous rocks, has an dance of dolomite pebbles derived from the Silurian s of the Lake Michigan region, and is associated considerable sand and gravel. At several outcrops ulton and Peoria Counties, a zone of sand and gravel minated silt occurs within the Illinoian drift, sepa- g an older till from the younger surficial till.

inoian drift south of the Sangamon River and Salt k is composed of till with considerable associated and gravel. From the hilly tract of Illinoian drift in southeastern Mason County a belt of crevasse ridges and kames extends southeastward across eastern Menard, western Logan, and northeastern Sangamon Counties. These ridges and kames contain sand deposits that are more or less restricted to the ridges and knobs themselves; subsurface records of borings in the intervening flats show mainly till and other fine-grained material.

Deposits in the Middletown and Athens bedrock valleys (figs. 9 and 10) and in the bedrock valleys at Petersburg and east of Chandlerville (fig. 10) are largely Illinoian and older till, with locally thick beds of sand and gravel.

Well MEN 19N5W-13.2h (Middletown Village Well 1) penetrated the following section as interpreted from drilling samples:

	Thickness (ft)	Depth to base (ft)
Pleistocene Series		
Wisconsinan Stage		
Silt, brown, noncalcareous	5	5
Illinoian Stage		
Till, yellow, very silty, noncalcareous	10	15
Till, yellow, noncalcareous	10	25
Sand, yellow, fine to medium, dirty, calcareous	5	30
Till, yellow, calcareous	25	55
Silt, brownish gray, calcareous	5	60
Till, yellow, brownish gray to brown, calcareous	15	75
Silt, gray-buff to yellow, calcareous	27	102
Sand, fine to medium, dirty, calcareous	13	115
Sand, gray, fine to coarse; gravel, granular, calcareous	35	150
Sand, gray, fine to coarse, calcareous	5	155 (total depth)

The well is located on the western flank of the Middletown bedrock valley. Farther east in the valley the drift probably attains a thickness of more than 250 feet.

The interbedding of deposits of differing permeabilities makes hydrologic conditions in the Illinoian upland east of Crane Creek more complex than those in the Wisconsinan terrace areas where the deposits are dominantly sand and gravel. Till or silt beds of low permeability limit recharge and also partially separate or confine water in aquifers. Because of the irregularity of the deposits, probably no given set of hydrologic conditions persists for wide areas. At some locations, beds of Illinoian sand and gravel yield ground water to relatively shallow drilled or dug wells, whereas at other locations it is necessary to drill several hundred feet to reach the Sankoty Sand in order to obtain adequate ground-water supplies. In some areas ground water is apparently "perched" above beds of low permeability that also confine the water in underlying sands and gravels.

There is some indication that the Sangamon weathered zone at the top of the Illinoian deposits affects the quality of ground water. Methane, or marsh gas, which may be related to the Sangamon zone, is reported at a

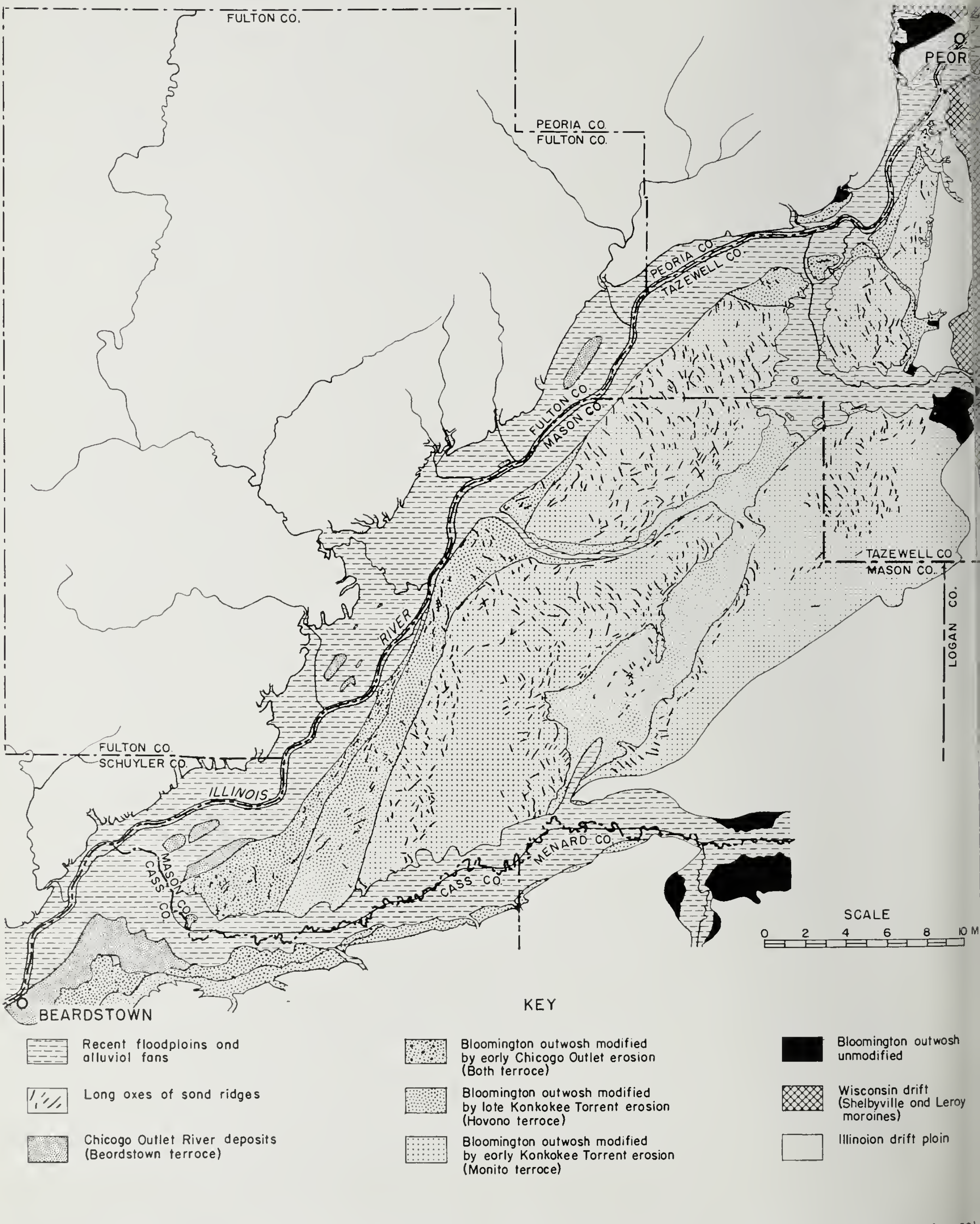

FULTON CO.
PEORIA CO.
FULTON CO.
PEOR
PEORIA CO.
TAZEWELL CO.
FULTON CO.
MASON CO.
RIVER
ILLINOIS
FULTON CO.
SCHUYLER CO.
MASON CO.
CASS CO.
CASS CO.
MENARD CO.
TAZEWELL CO.
MASON CO.
LOGAN CO.
BEARDSTOWN
SCALE
0 2 4 6 8 10 M
KEY
Recent floodplains and alluvial fans
Long axes of sand ridges
Chicago Outlet River deposits (Beardstown terrace)
Bloomington outwash modified by early Chicago Outlet erosion (Bath terrace)
Bloomington outwash modified by late Kankakee Torrent erosion (Havana terrace)
Bloomington outwash modified by early Kankakee Torrent erosion (Manito terrace)
Bloomington outwash unmodified
Wisconsin drift (Shelbyville and Leroy moraines)
Illinoian drift plain

Fig. 17. Distribution of terraces and pattern of sand ridges in the Illinois Valley from Peoria to Beardstown (Wanless, 1957, fig. 59).

pth of about 60 feet in several wells between Easton d Mason City. In approximately the same area, the ound water has higher concentrations of nitrates, ich perhaps are related to oxidation of ammonia in ried soil zones.

sconsinan Outwash

Visconsinan (Bloomington) outwash deposits under- the terraces (fig. 12) at shallow depths. They are ensively overlain by wind-blown sand and silt, and silt and peat along some of the low swampy areas acent to streams. The outwash consists of sandy vel with beds of pebbly sand at the northern edge of terrace area near Pekin, and grades southward to d with scattered pebbles and gravel lenses.

'he grains of the sand outwash are 60 to 75 percent rtz, 10 to 20 percent feldspar, and 20 to 30 percent mentary and crystalline rocks and minerals. The l is commonly light brown to yellowish brown and tains fairly abundant yellowish grains of quartz and spar, scattered fragments of pearly mollusk shells, rod-like spicules (from fresh-water sponges?) and er-colored spores.

he pebble-sized gravel (coarser than 4-mesh) is made dominantly of dolomite (30 to 38 percent noted in lom counts), limestone, and chert, and also has sub- tial numbers of igneous and metamorphic rock oles. An exposure of the gravel reported in a pit at rpool (Wanless, 1957, p. 143) shows 2½ feet of nt silt and sand over 5 to 6 feet of flat-bedded sandy el, which in turn overlies 10 to 11 feet of cross- led gravel with foreset beds dipping west-southwest ngles of 20° to 25°. The cross-bedded gravel is mington outwash, which retains the structure left ediment-choked, braiding meltwater streams.

nce the Manito, Havana, and Bath Terraces repre- various levels of erosion of the original Blooming- outwash fan, the Wisconsinan deposits are corre- dingly thinner under each lower terrace. The maxi- thickness of the Wisconsinan outwash beneath the to Terrace is probably about 100 feet, although the of the deposits are masked by thick dune sand or lluvial silts.

sample study log of well TAZ 23N5W-26.8a at Valley, on the Manito Terrace, shows the nature Wisconsinan and Sankoty deposits.

	Thickness (ft)	Depth to base (ft)
ocene Series		
consinan Stage		
Silt, black, dark brown, carbonaceous	3	3
Silt, dark yellowish brown, noncalcareous	9	12
Sand, medium to coarse, with gravel, yellowish brown; abundant dolomite, limestone, and chert	10	22
Sand, medium to coarse, yellowish brown, very silty	5	27
Sand, medium to coarse, with granule gravel, yellowish brown, very silty	14	41
Sand, fine, pale brown; subrounded grains; abundant white and yellow limestone and dolomite grains; some wood and mollusk fragments	59	100
Kansan Stage		
Sankoty Sand		
Sand, fine to very coarse, pinkish gray; abundant pink grains of quartz and feldspar	15	115 (total depth)

Wisconsinan outwash deposits are the coarsest and most permeable sediments of the region. Along with the Sankoty Sand, which they apparently immediately overlie in much of the area, they are the main aquifer, nearly everywhere exceeding 100 feet thick (fig. 14). The coarseness and, presumably, the permeability of the outwash generally increase from south to north, though the width of the valley and the presence of bedrock "islands" have locally influenced depositional conditions and the resulting textures of the sand and gravel.

Recharge to the Wisconsinan outwash and underlying Sankoty Sand is facilitated by the broad, hummocky areas of sand dunes on the terraces. Only small areas of outwash are covered by fine-grained sediments that restrict the infiltration of rainfall.

Wisconsinan Dune Sand

Sand ridges cover about 375 square miles of terrace east of the Illinois River and also occur on the east bluffs and uplands east of the Illinois Valley in Mason and Cass Counties. The distribution and orientation of the ridges, which probably originated from wind modification of bars of sandy outwash, are shown in figure 17 (Wanless, 1957, p. 145). Most ridges are at an angle to the trend of the Illinois, Mackinaw-Quiver Creek, and Crane Creek Valleys, but the ones near the valleys generally curve to lie approximately parallel to the valleys. Wanless (1957, p. 176) attributed the orientation of the sand ridges to overflow currents that first diverged from the valleys and then, when the water level subsided, were confined to the valleys. The first modification of ridges by wind action was probably right after subsidence of the Kankakee Flood, before vegetation was well established. Further modification by wind has taken place at various times since then.

Many of the sand ridges are 40 to 50 feet high, and a few are as much as 80 feet high. The wind-blown sand mantles outwash bars and in some places forms ridges and knobs without cores of outwash. In extensive areas the dune sand is more than 20 feet thick. A sandy soil 1 or 2 feet thick is developed on the dunes, though the wind has excavated blowouts in some places where the natural vegetation has been removed.

Commonly, 30 to 70 percent of the grains in the dunes are in the medium sand range, the rest being finer. Cumulative frequency curves of representative dune sand samples are shown in figure 18. Excellent sorting is indicated by the steepness of the curves. Thirteen samples average 48 percent medium sand and .0107 inches median diameter. The sand is generally finer grained in dunes along the east edge of the terrace near Kilbourne and Easton. On the upland near Mason City, the sand is still finer grained, one sample just west of Mason City having a median diameter of .007 inches (fine sand) and containing only 10 percent medium sand.

The rough dune topography of ridges, knolls, and blowouts, with highly permeable soils and absence of integrated drainage, provides favorable conditions for the infiltration of rainfall. The dune sand itself is not a significant part of the aquifer, generally being above the water table.

Wisconsinan Loess and Silt

Uplands bordering the terraces east of the Illinois River are mantled by some of the thickest loess deposits in the state (fig. 7). The area of thickest loess, shown as exceeding 300 inches on uneroded topography in figure 19, includes part of the Illinoian upland south of the Sangamon River and Salt Creek in Cass and Menard Counties, and the triangular Illinoian upland in eastern Mason County and northwestern Logan County. Here the loess is generally more than 10 feet and often more than 30 feet thick. Loess thicknesses of 68 and 92 are reported at two localities on the bluffs near Ch lerville in Cass County (Smith, 1942, p. 157).

A traverse from Menard County southeastw (Smith, 1942) shows that the loess decreases rap in thickness and coarseness within 2 miles of the b then thins and becomes finer textured at a gradual for the next 50 miles. Within 2 miles of the bluff, 20 percent of the loess is sand, but farther away o percent or less is sand. The mean diameter decreas .024 millimeters (mm) at 3.8 miles, .024 mm at miles, .022 mm at 14.7 miles, and .017 mm at 42 (Smith, 1942, p. 154-156).

Loess overlying the Wisconsinan upland east of Il van and the Bloomington outwash (fig. 12) is erally only 5 to 10 feet thick, whereas the you Wisconsinan terraces are relatively free of loess.

The Wisconsinan loess and silt are not impo sources of ground water, though they provide s supplies to a few dug wells, especially on the Illi upland east of Crane Creek where they are thick contain considerable sand. They are moder permeable.

Wisconsinan Upland Drift

The Wisconsinan undifferentiated drift sheet f a ridged upland plain that rises above the Illi

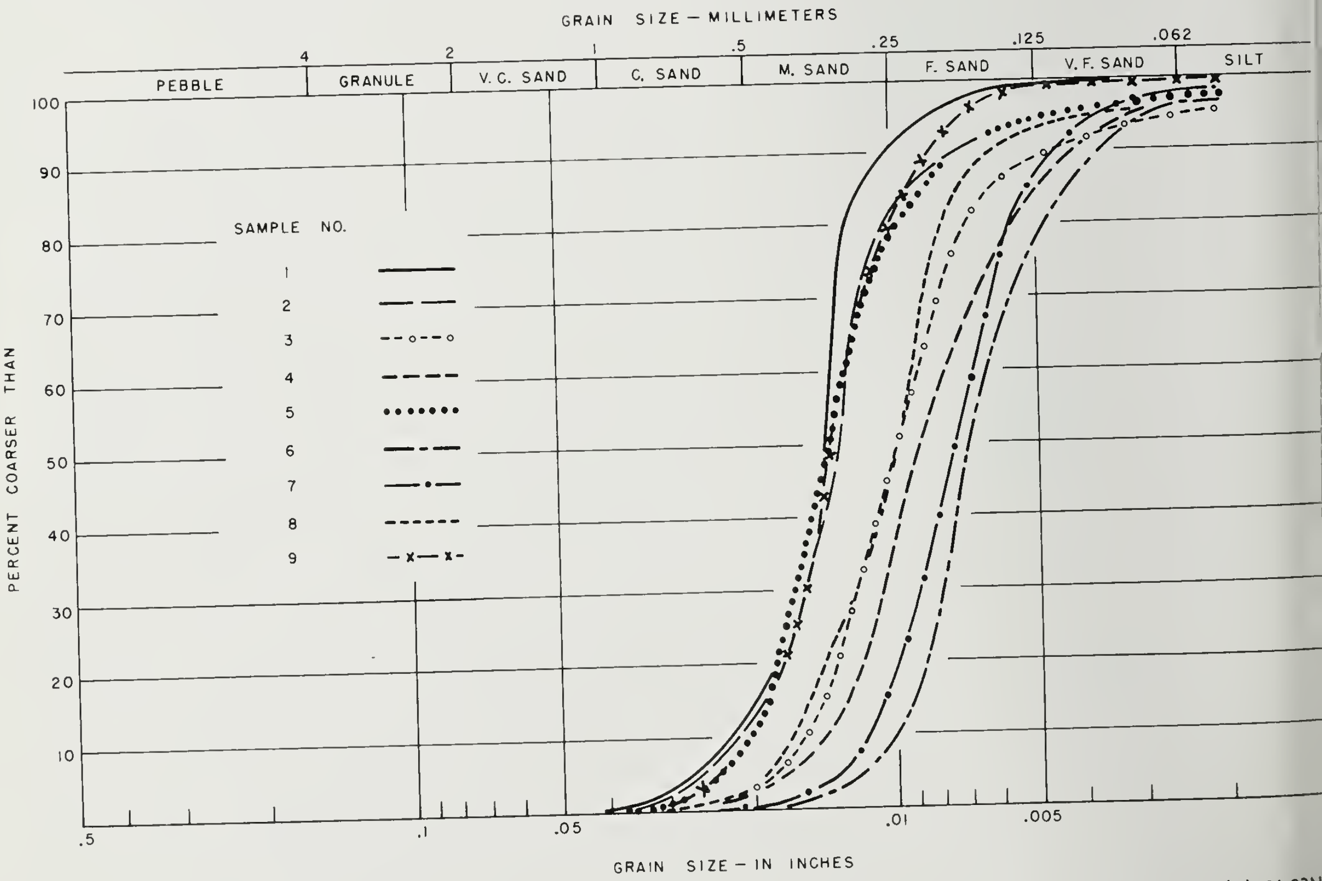


Fig. 18. Sieve analyses of dune sand. Location from which the samples were taken are (1) 21-23N-7W (depth 6 ft); (2) 21-23N (depth 4½ ft); (3) 16-23N-7W; (4) 22-22N-7W; (5) 33-22N-8W; (6) 12-20N-6W; (7) 33-20N-8W; (8) 18-20N-9W; (9) 9-19N-1

n and Wisconsinan terraces north and east of Dela- (figs. 12 and 13, E—F). It is mantled by 5 to 10 of loess. Delavan is situated on the lower frontal ion of the Shelbyville end moraine, which forms outermost ridge of the Wisconsinan drift plain.

'isconsinan till is brownish to pinkish gray or on-gray, somewhat more clayey, less sandy, and compact than the underlying Illinoian till. A ers log of well TAZ 22N4W-9.1d in Delavan records following section:

	Thickness *(ft)*	Depth to base *(ft)*
and clay	20	20
clay	25	45
	20	65
	10	75
pan	20	95
and gravel	25	120
l	27	147 (total depth)

e "soil and clay," "blue clay," and "drift" prob- represent Wisconsinan loess and till, the "clay" 65 to 75 feet is lower Wisconsinan loess, the "hard- ' is Illinoian till, and the sand and gravel are ian and older deposits. The maximum thickness e Wisconsinan deposits near Delavan is about 125

ce the Wisconsinan deposits of the upland are ly clayey till with little associated sand and gravel, rge conditions are less favorable than on the Wis- nan terraces or on the Illinoian drift upland. It nerally necessary to drill through the Wisconsinan and till and into Illinoian and older sand and l to obtain ground-water supplies east and north elavan.

nt Deposits

ent deposits include those made under present-day tions by running water, standing water, wind, and isms. They occur mainly in the floodplains (fig. nd at the base of steep slopes. The floodplains are ally floored with clay, silt, and sand deposited by waters and by slope wash from the loess-covered ds. In addition, the Illinois River floodplain con- a number of lakes in which silt and mud from , plant debris, and some shells have accumulated. sits coarser than those in the floodplains occur in n channels. Although the rivers have low gradients re sluggish streams under normal conditions, they rapidly during floods and deposit sand bars that xposed at low-water stages.

general, the thickness of the Recent alluvium along linois River is a measure of the scouring effect of ver since the last glaciation. Deepest scouring oc- luring the spring floods and in the winter when ice jams cause the river to deepen its channel to pass beneath the ice. The effect of scour, in combination with channel migration, has been to produce an upper blanket of Recent alluvium that coarsens with depth as a result of successive periods of scour and deposition, with the coarsest particles settling out first. The uppermost portion of the alluvium contains only fine-grained material; its thickness is increased at the surface by deposition of silt and clay from flood waters that cover the area after the river channel has migrated to a new position.

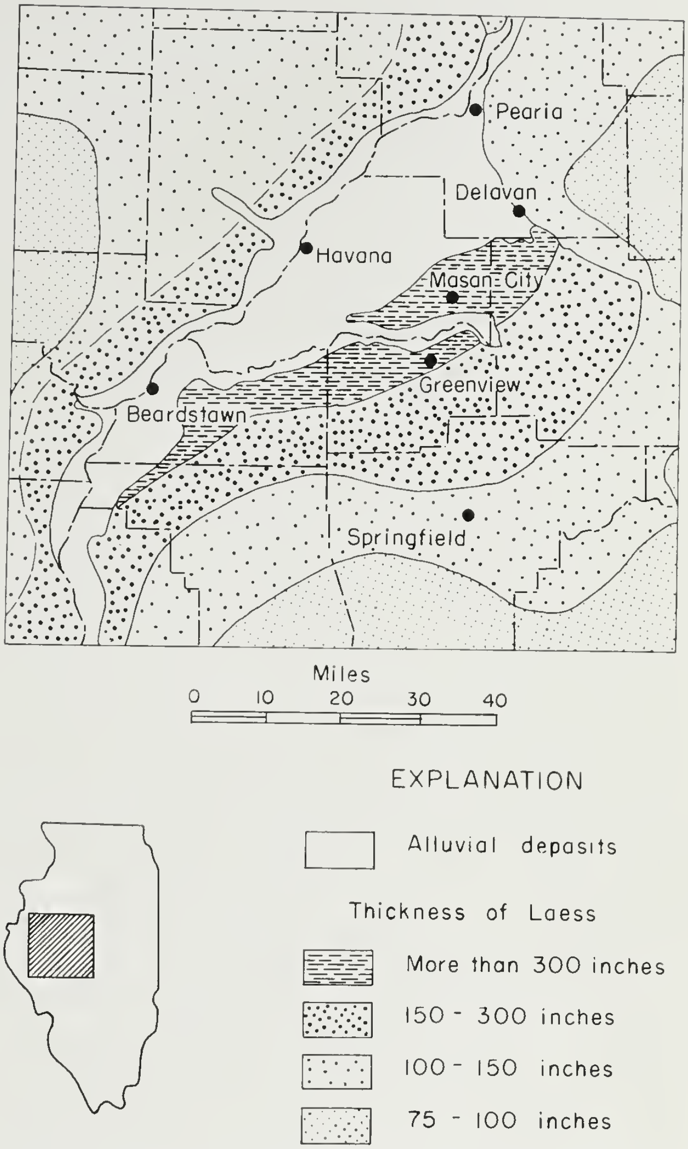


Fig. 19. Thickness of loess on uneroded topography. (After Smith, 1942, fig. 3.)

As suggested in figures 13 and 14, the floodplain of the Illinois River from Havana to Kingston Mines and from Frederick to north of Browning is underlain by less than 50 feet of unconsolidated deposits. The deposits beneath and west of the river in these stretches are mainly Recent alluvium. Between Browning and Havana the alluvium is underlain by glacial outwash.

GROUND WATER

Source, Movement, and Occurrence

The general principles underlying the source, movement, and occurrence of ground water have been presented in papers by Meinzer (1923, 1932, and 1942), and Wenzel (1942), among many others. The following discussion is a brief outline of those general principles that are essential to an understanding of ground-water conditions in the Havana region.

Ground water is derived from precipitation that falls mainly as rainfall and seeps into the ground. The water infiltrates through loose particles of the soil and percolates downward. Below a certain depth all openings in the earth materials are filled with water. *Ground water* is defined as water in the zone of saturation. The process of addition of water to the ground-water reservoir is called *recharge*.

Openings in which ground water is stored in the zone of saturation range in size from tiny pores between particles of clay and silt to large crevices in dolomite and limestone. The *porosity* of an earth material refers to its pore space and is expressed quantitatively as the percentage of its total volume.

Earth materials that have interconnected openings large enough to store and transmit water readily into a well or spring are called *aquifers*. The capacity of an earth material to transmit water under pressure is called its *permeability*.

The upper limit of the saturated zone is called the *water table*. The water immediately below the water table is unconfined and can rise or fall freely as water is added or withdrawn. In wells that penetrate the saturated zone under such conditions, the water level indicates the elevation of the water table; such wells are called *water-table wells*.

Under natural conditions, the water table roughly parallels the surface topography, rising under the uplands and intersecting the ground surface along perennial streams, lakes, and swamps into which ground water is discharged by gravity flow from adjacent areas where the water table is higher. The position and shape of the water table may be modified by the kind of rocks present or by other factors affecting permeability. The position of the water table and the discharge of ground water to streams fluctuate from season to season and year to year.

If a permeable water-bearing formation, or aquifer, is confined between nonpermeable beds and water is supplied to it from a higher elevation, the water is confined under hydraulic pressure. When such an aquifer is penetrated by a well, water will rise above the aquifer in the well to a height equal to the hydraulic head of the aquifer. Ground water that is confined under pressure in this manner is said to be under *artesian conditions*. Wells penetrating such aquifers are called *artesian wells*. If the hydraulic head is above land surface at the well, the well will flow.

To supply a producing well, ground water must n
through the aquifers toward the well. Under water-t
conditions, pumping lowers the water table in the
cinity of the well and induces the flow of ground w
toward the well from adjacent areas. Under arte
conditions, pumping causes, in the vicinity of the
a reduction of hydrostatic pressure that induces the
of ground water toward the well. The aquifer u
artesian conditions is not dewatered but remains
because the discharged water is derived by the com
tion of the aquifer and associated beds, by the expan
of the confined water, and by flow from the rech
area. The compaction of the aquifer and associated
and expansion of confined water constitute the sto
factor of an artesian aquifer.

The depression of the water table, or the reductio
artesian pressure, that results from pumping takes
form of an inverted cone with the well at the center,
is called the *cone of depression*.

The measurement of the elevation of the water
or artesian pressure surface is made by determining
water levels in wells. Two types of water levels are re
nized: nonpumping levels and pumping levels.

The *nonpumping level* is the level at which the w
stands in a well not influenced by pumping in the
mediate vicinity of the well. The level may change
long periods of time, and it also may be affected by
gional pumpage and changes in barometric pressure
is of great importance in evaluating the water reso
of a region.

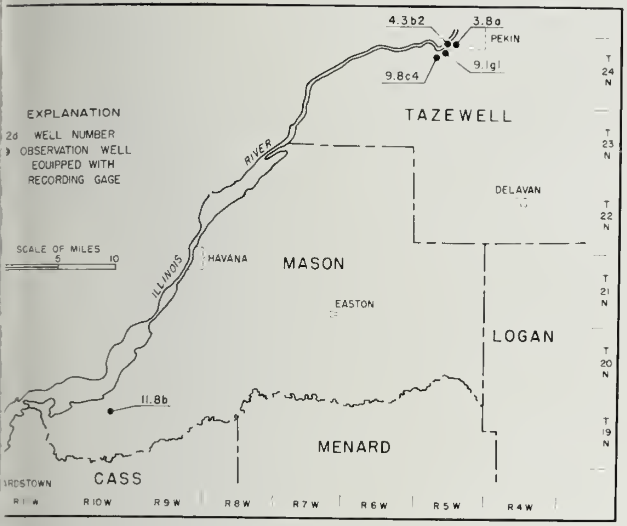
The *pumping level* is the level to which the water
face falls in a well during pumping. This level dep
on rate and duration of pumping, permeability
thickness of the aquifer, and well characteristics.

The difference between the nonpumping level and
pumping level in a well is called *drawdown*. The d
down is a temporary lowering of the water level d
pumpage in the well. When the pump is stopped
water level rises. This rise in the water level is c
recovery. The yield of a well in gallons per minute
foot of drawdown is the *specific capacity*.

A continued lowering of the nonpumping level
region is called a water-level *decline*. Decline of
level is usually caused by excessive pumpage, dive
of recharge, or drought.

Water-Level Fluctuations

Water levels in wells are almost constantly fluctu
and decline or rise a fraction of an inch or many
within a relatively short time. Water levels in wel
artesian aquifers generally fluctuate to a much gr
extent than water levels in water-table aquifers an
sensitive to such factors as changes in atmospheric
sure, earthquakes, earth tides, and changes in su
loading. Artesian wells also are influenced by



0. Location of observation wells equipped with recording gages.

rals from wells and springs and by recharge from
ipitation, although the effects of recharge are some-
s not immediately noticeable.

ater levels in water-table aquifers are affected by
t recharge from precipitation, evapotranspiration,
drawals from wells, discharge to streams, and
ges in surface-water stage. Fluctuations in water
s indicate changes in the actual quantity of water
d in aquifers and movement of ground water. The
unt of water taken from or added to storage per unit
ge in water levels is generally many times larger
r water-table conditions than under artesian con-
ns.

e water table in the Havana region under natural
itions recedes in late spring, summer, and early fall,
discharge by evapotranspiration and by ground-
r runoff to streams is greater than recharge from
pitation. Water levels begin to recover in wells late
e fall, when evapotranspiration losses are small and
itions are favorable for the infiltration of rainfall,
to replenish depleted soil moisture and later to per-
e to the water table. The rise of water levels is
ially pronounced in the wet spring months, when
round-water reservoir receives most of its annual
rge. The high and low points of the annual cycle
ter levels occur at different times from year to year,
nding in large part upon the seasonal and areal dis-
tion and intensity of rainfall.

perimposed on the annual cycle are changes in
r levels caused by pumping. Pumping lowers water
s in the vicinity of the well until (1) a hydraulic
ient is established from a source of recharge to the
ed well sufficient to bring from the recharge area
mount of water being pumped, (2) sufficient water
erted from an area of discharge to balance pump-
or (3) a combination of increased recharge and
ted discharge balances the pumpage.

determine the character and magnitude of water-
fluctuations, recording gages were maintained for a number of years on two wells in the southern part of the Havana region and on four wells in the northern part (fig. 20). Descriptions of these wells are given in table 2. Monthly water levels in wells CSS 18N12W-15.4g and MSN 19N10W-11.8b in the southern part for 1957 through 1960 are shown in figure 21; daily water

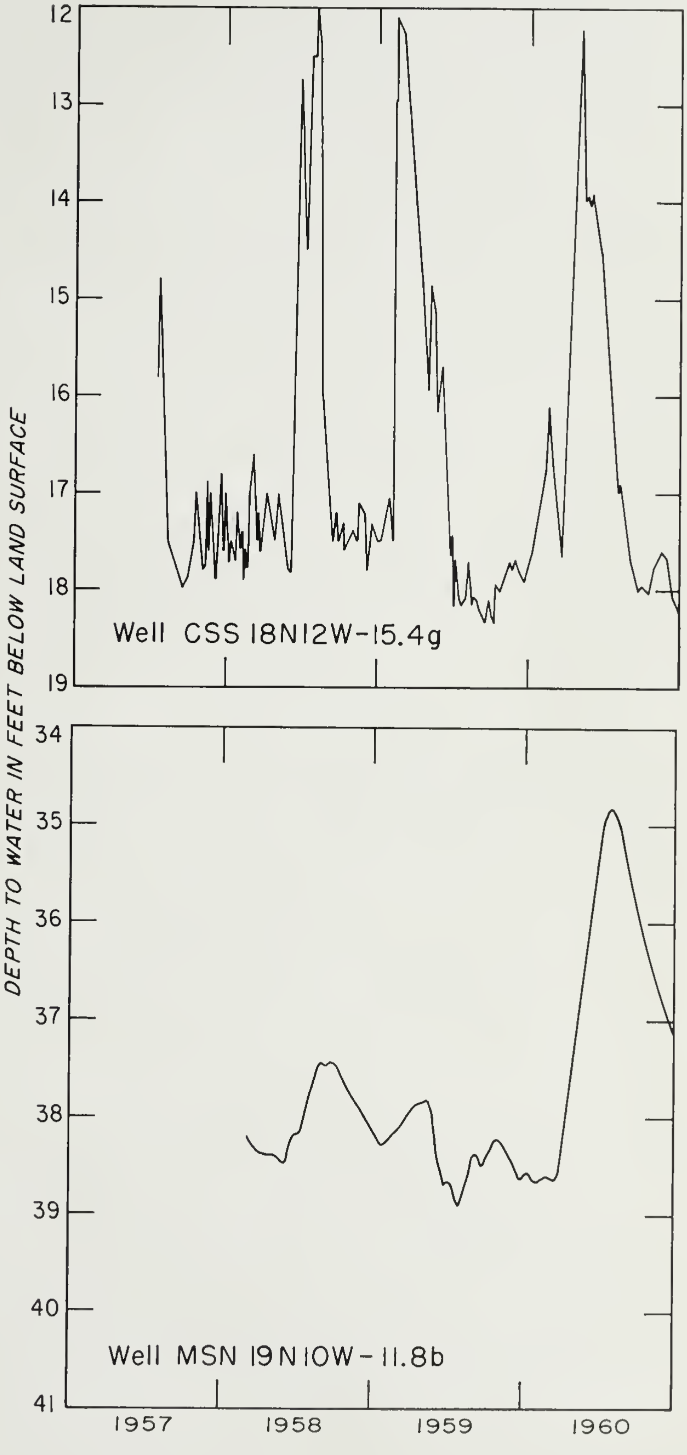


Fig. 21. Water levels in wells in the southern part of the region, 1957-1960.

levels for these wells and Illinois River stages at Beardstown during 1958, 1959, and 1960 are shown in figure 22. Monthly water levels in wells TAZ 24N5W-4.3b2, -3.8a, -9.1g1, and -9.8c4 in the northern part of the region for 1943 through 1961 are shown in figure 23; daily water levels in these four wells and Illinois River stages at Pekin during 1960 are shown in figure 24. The water levels shown are nonpumping water levels.

The close correlation between ground-water levels and Illinois River stages is apparent from the data for well CSS 18N12W-15.4g (fig. 22). The well is about 50 feet from the river's edge at the city of Beardstown. Except during periods of high river stage, water levels in
well are above the surface of the river and there is
charge of ground water into the river. Well M
19N10W-11.8b is much farther from the river (abo
miles) and is little affected by changes in the river st
(fig. 22). Water levels in this well reflect, for the
part, seasonal variations in recharge directly from
cipitation. During most years water levels in well M
19N10W-11.8b fluctuate less than 2 feet.

As shown by the hydrograph of well TAZ 24N
9.1g1 (fig. 24), water levels in the pumping center
of Pekin decline rapidly during each 5-day work
and recover during weekend industrial shut-do
Superimposed on these weekly cycles are change
water levels caused by daily pumpage cycles. In gen
there is a close correlation between major river
changes and water-level fluctuations in the hea
pumped area. Water levels in wells TAZ 24N5W-4
and TAZ 24N5W-9.1g1 are below the surface of the
at all times, whereas water levels in wells TAZ 24N
9.8c4 and TAZ 24N5W-3.8a are at times above the
face of the river. Hydrographs (fig. 24) and water-

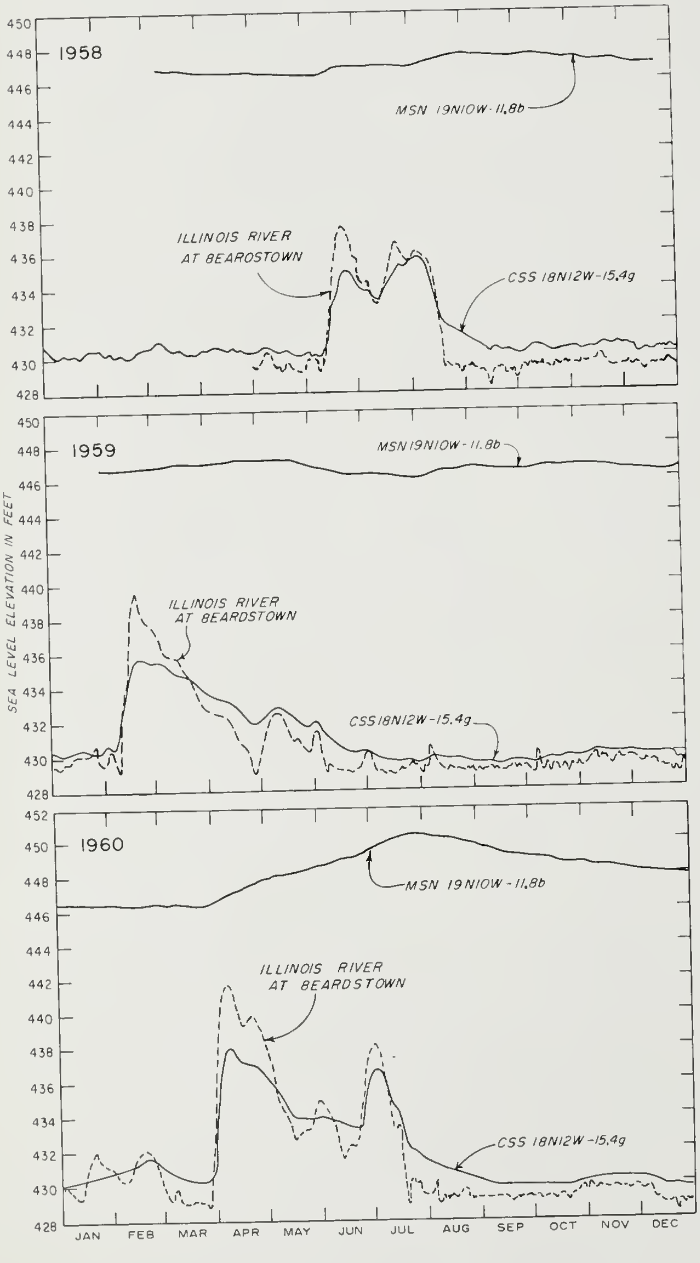


Fig. 22. Water levels in wells in the southern part of the region and Illinois River stages at Beardstown, 1958-1960.

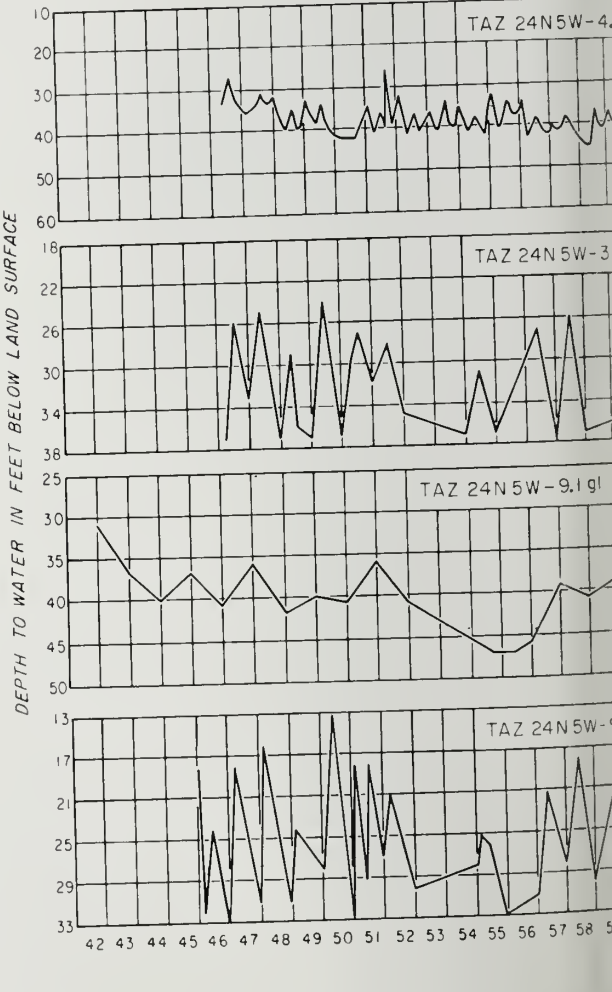


Fig. 23. Water levels in wells in the northern part of the
1943-1961.

Table 2. Descriptions of Selected Observation Wells

Well number	Owner	Well: Depth (ft)	Well: Diameter (in)	Screened interval (ft below land surface)
18N12W-15.4g	U.S. Corps of Engineers	74	12	64–74
19N10W-11.8b	Harold Banks	40	42	Open end
24N5W-3.8a	Corn Products Refining Co.	83	26	63–83
24N5W-4.3b2	American Distilling Co.	85	24	65–85
24N5W-9.1g1	Standard Brands, Inc.	76	25	51–76
24N5W-9.8c4	Commonwealth Edison Co.	65	24	25–65

ours (figs. 25 and 26) suggest that ground water drawn from the pumping center consists partly of r that under natural conditions would have disged into the river and partly of water induced to from the river into the cone of depression. Water s in the pumping center (figs. 23 and 24) fluctuate than 15 feet during the year; however, there is no nuous long-term decline, suggesting that in the past irge has balanced discharge.

Configuration of the Water Table

gure 25, prepared from data (table A, appendix) ted in 103 observation wells, shows contours on the r table in the Havana region in 1960. Figure 13 s geologic cross sections and profiles of the water . The water-table contours indicate the configura- of the water table, areas of recharge and discharge ound water to streams, and the direction of groundmovement. A study of the location of pumping rs and figure 25 suggests that, with the exception e area immediately south of Pekin, contours have not been distorted to any great degree by pumping. In most of the region, present pumpage has not appreciably affected the water table.

The water table conforms generally to the configuration of the land surface. Its slope is greatest in the vicinity of parts of the Illinois River where the glacial materials are thin and is least at places where the glacial materials are thick and very permeable. Ground water moves, in general, from uplands in the east towards the Illinois River. The water table slopes from an elevation of about 540 feet east of Delavan to about 440 feet along the Illinois River. The average slope is about 3.5 feet per mile.

Ground water locally moves in all directions toward small streams and drainage ditches and to the Mackinaw, Sangamon, and Illinois Rivers. Contours warp upstream, indicating discharge of ground water to these streams.

The contour maps in figure 26, prepared from data (table A, appendix) collected in 40 observation wells, show elevations of the water table in the pumping center south of Pekin in May and August, 1962. The illustration shows clearly the cones of depression in the water table that have developed as the result of heavy pumping. Pronounced cones are centered at the well fields of industries in the area. A ground-water mound appears in the vicinity of a recharge pit near the center of the area. The 440 and 435 water-table contours bend irregularly around intake and discharge canals and roughly parallel the river's edge.

Storage

The amount of water in storage in the aquifers in the Havana region is determined by the areal extent of the aquifers, their saturated thicknesses, and their porosity. A portion of the stored water is free to drain by gravity; the remainder is retained in the pores of the aquifers by

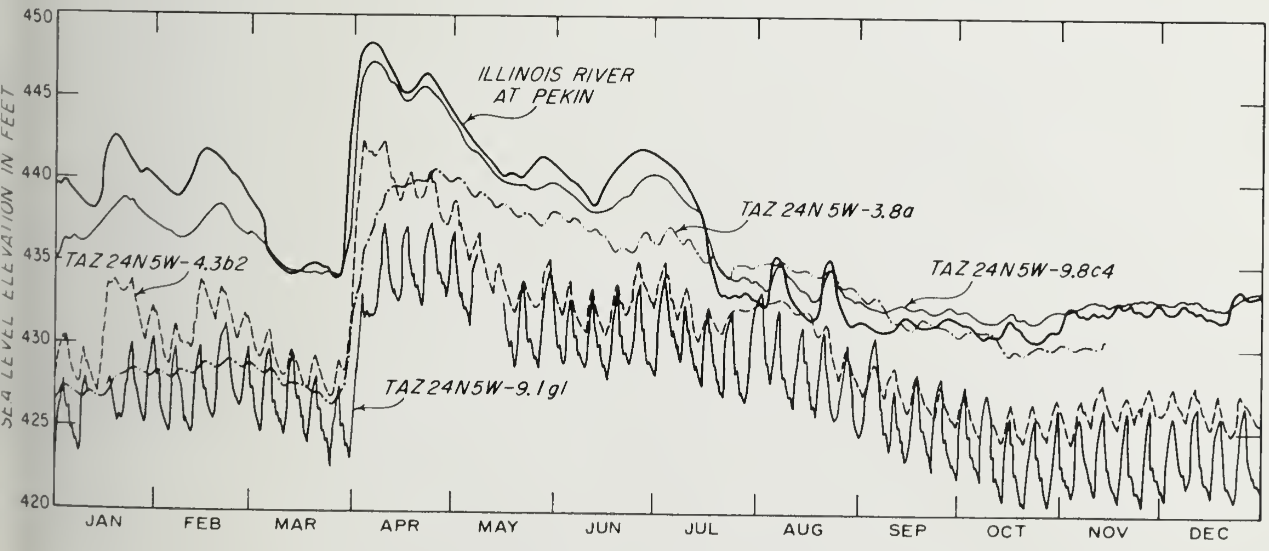


Fig. 24. Water levels in wells in the northern part of the region and Illinois River stages at Pekin in 1960.

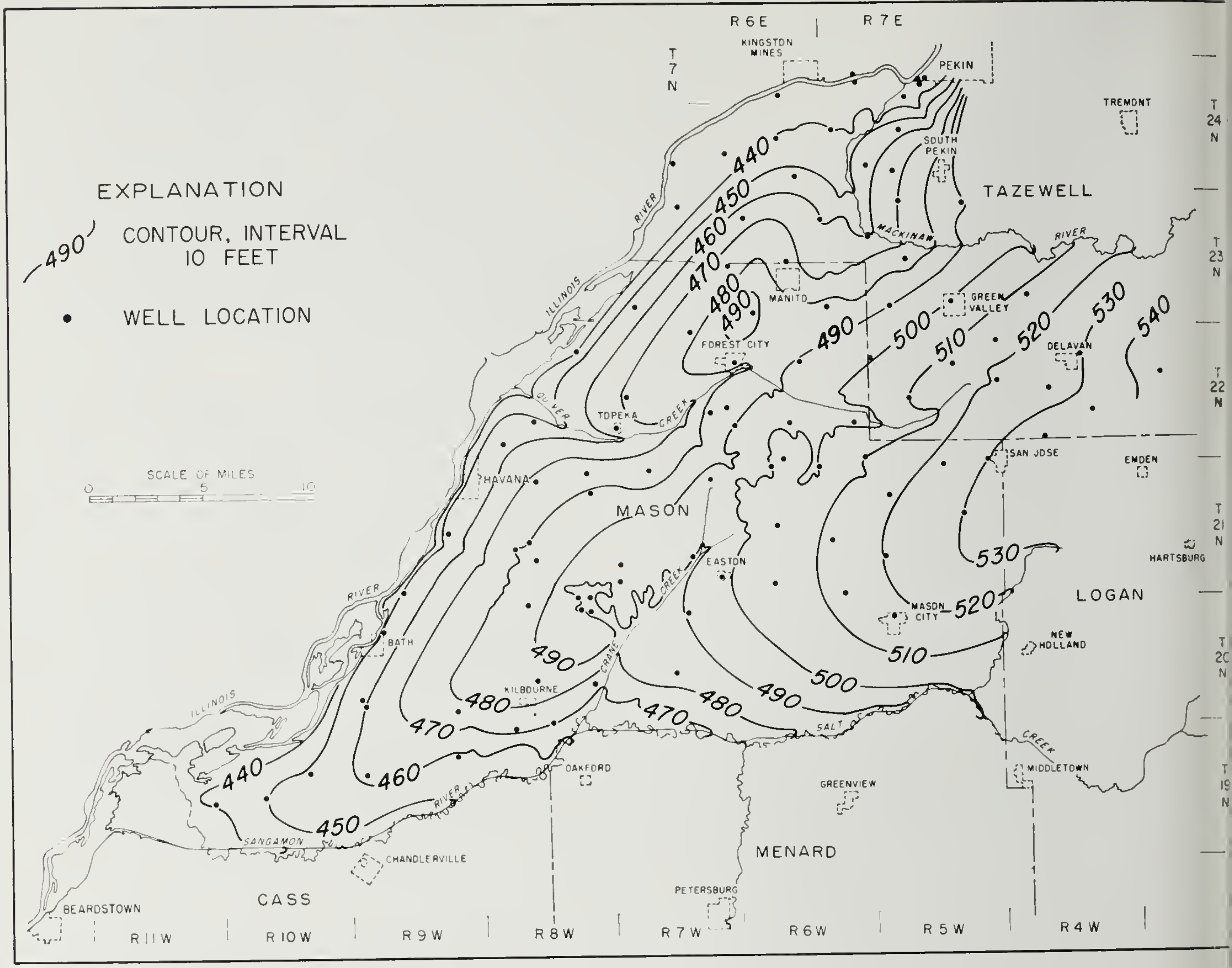


Fig. 25. Approximate elevation of the water table in the Havana region in 1960.

molecular attraction. However, not all the water that is free to drain by gravity can be practically withdrawn through wells.

A map (fig. 27) showing the saturated thickness of the unconsolidated deposits in 1960 was prepared from the water-table and bedrock-surface contour maps. The total volume of saturated unconsolidated deposits in the region was computed to be about 2.75×10^{12} cubic feet. The saturated thickness is greatest (170 feet or more) in the channel of the buried valley south of Delavan, north of Mason City, at Forest City, and east of Havana. It exceeds 100 feet in most of the region and is less than 60 feet at places in the vicinity of the Illinois River. The unconsolidated deposits are comparatively thin above bedrock terraces adjacent to valley walls.

The deposits underlying the Wisconsinan terraces (fig. 12) are essentially sand and gravel from surface to bedrock. Porosities of the cleaner portions probably range from 30 to 40 percent. The deposits underlying the Illinoian and Wisconsinan uplands, roughly east of Easton, Delavan, and Green Valley, consist of silts, and sands and gravels, with about half of the se sand and gravel (fig. 13). Porosities of the finer ments probably exceed those of the sands and grav

The average porosity of all unconsolidated deposi estimated to be about 35 percent. The quantity of w in storage, therefore, is about 7.2×10^{12} gallons. I a study of the water-yielding properties of the aqu in the region and of the values of specific yield d mined for a comparable area of sand and gravel an sociated sediments at Louisville, Kentucky (St 1944), the average specific yield of all unconsolid deposits is estimated to be 20 percent. If the ave specific yield of the aquifers is 20 percent, a 4.1×10^{12} gallons of water could be made available storage in the region by completely dewatering th consolidated deposits. The complete dewatering o aquifers is impractical, however, for the yields of fall off rapidly as the saturated thickness of the aq is greatly reduced.

Hydraulic Properties of Aquifers

ie yields of wells, quantity of water moving through quifer, and the magnitude of water-level fluctuations to recharge and discharge of ground water are ely dependent on the hydraulic properties of an fer. The principal hydraulic properties of an aqui- are the coefficients of transmissibility, T, or per- bility, P, and storage, S.

ie capacity of a formation to transmit ground water pressed by the *coefficient of transmissibility,* which fined as the rate of flow of water in gallons per day ugh a vertical strip of the aquifer 1 foot wide and iding the full saturated thickness under a hydraulic ient of 100 percent (1 foot per foot) at the prevail- temperature of the water. The coefficient of trans- ibility is the product of the saturated thickness of iquifer, m, and the *coefficient of permeability,* which fined as the rate of flow of water in gallons per day igh a cross-sectional area of 1 square foot of the fer under a hydraulic gradient of 100 percent at the ailing temperature of the water.

ie storage properties of an aquifer are expressed by *oefficient of storage,* which is defined as the volume ater released from or taken into storage per unit ice area of the aquifer per unit change in the water Under water-table conditions, the coefficient of ge is equal to the specific yield, provided gravity iage is complete.

e manner in which T and S are related to water- decline and the yields of wells can best be illustrated discussion of the cone of depression. The shape of one is controlled in part by the permeability of the er. With other factors remaining constant, the the permeability, the steeper will be the gradient e cone of depression and the greater will be the down in a well.

ring the initial period of pumping, discharge is ced by water taken from storage within the aquifer to the well. As pumping continues, a larger per- ge of water is taken from storage at greater dis- s from the well. The larger the coefficient of stor- he smaller the water-level decline required to obtain storage the amount of water being pumped.

th continuous pumping, the cone of depression s in size and depth at a diminishing rate until hy- ic gradients are established sufficient to capture h recharge to balance the amount of water pumped. ded the aquifer is infinite in areal extent, the di- ons of the cone of depression depend upon the hy- ic properties of the aquifer, the pumping rate, and umping period. Water-level decline is directly pro- nal to the pumping rate and diminishes in a loga- ic manner outward from the well. In a multiple- system the cones of individual wells overlap and is mutual interference between wells. The amount erference depends in part on the hydraulic proper- f the aquifer and is directly proportional to pumping rates and inversely proportional to the logarithm of the distances between wells.

Aquifer tests

The hydraulic properties of an aquifer may be determined by means of aquifer tests, wherein the effect of pumping a well at a known constant rate is measured in the pumped well and in observation wells penetrating the aquifer. Graphs of drawdown versus time after pumping started, and/or of drawdown versus distance from the pumped well, are used to solve equations that express the relation between the coefficients of transmissibility and storage of an aquifer and the lowering of water levels in the vicinity of a pumped well.

The nonequilibrium formula (Theis, 1935) is the equation most commonly used to determine hydraulic properties with aquifer-test data. The nonequilibrium formula is:

$$s = (114.6\,Q/T)\ W(u) \qquad (1)$$

where:

$$W(u) = \int_u^\infty e^{-u}/u \,\mathrm{du} = -0.5772 - \ln u + u - (u^2/2.2!) + (u^3/3.3!) - (u^4/4.4!) \quad . \quad . \quad .$$

and

$$u = 2693 r^2 S/Tt \qquad (2)$$

s = drawdown, in feet (ft)

Q = discharge, in gallons per minute (gpm)

T = coefficient of transmissibility in gallons per day per foot (gpd/ft)

r = distance from pumped well to observation well, in ft

S = coefficient of storage, fraction

t = time after pumping started, in minutes (min)

Methods for solving the nonequilibrium formula were described by Cooper and Jacob (1946) and Ferris (1959).

The nonequilibrium formula is based on the following assumptions: (1) that the aquifer is homogeneous and isotropic; (2) that the aquifer is infinite in areal extent and is confined between impermeable beds; (3) that the coefficient of storage is constant; and (4) that water is released from storage instantaneously with a decline in water levels. Generally none of these conditions is completely fulfilled in nature, but in many areas they are substantially satisfied.

The existence of geohydrologic boundaries serves to limit the continuity of aquifers. Geohydrologic boundaries may be divided into two types, barrier and recharge. Barrier boundaries are lines across which there is no flow, and they may consist of folds, faults, or relatively impervious deposits such as shale or clay. Recharge boundaries are lines along which there is no drawdown, and they may consist of rivers and lakes hydraulically connected to aquifers. The influence of geohydrologic

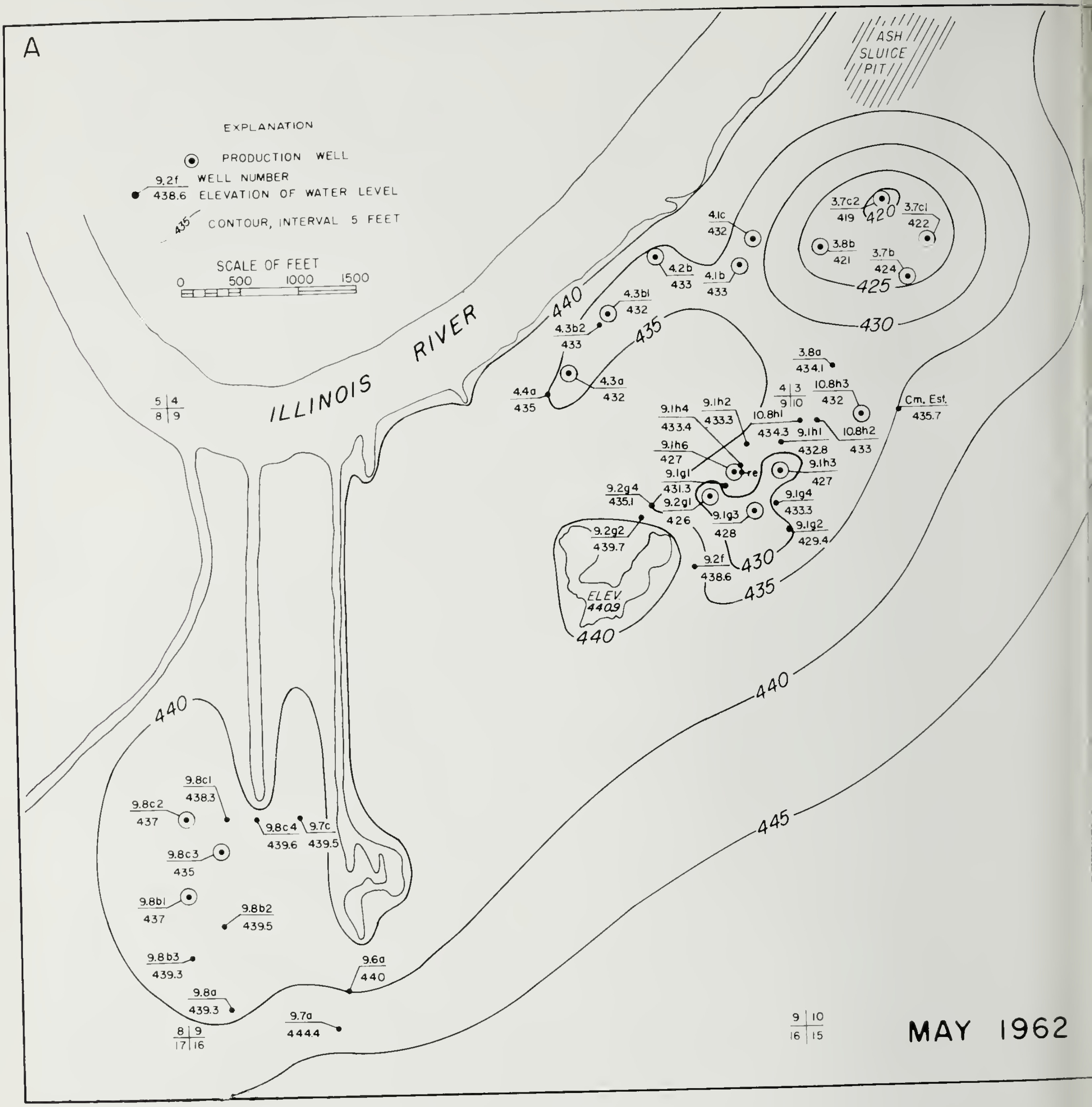


Fig. 26A. Approximate elevation of the water table in the northern part of the Havana region in May 1962.

boundaries on the response of an aquifer to pumping can be determined by means of the image well theory described by Ferris (1959).

During 1959 and 1960, six aquifer tests (fig. 28) were made by the State Water Survey in the Havana region to determine the hydraulic properties of the unconsolidated deposits. To illustrate methods of analysis, data for three aquifer tests are given in figures 29 through 32.

A summary of the coefficients of transmissibility and storage obtained from aquifer tests is given in table 3. These data indicate a considerable range in hydra properties from place to place within the region. I northern part of the region, the coefficient of pe ability ranges from 7500 to 15,000 gpd/sq ft and coefficient of transmissibility ranges from 150,00 500,000 gpd/ft. In eastern parts of the region, th efficient of permeability ranges from 2000 to gpd/sq ft and the coefficient of transmissibility ra from 200,000 to 275,000 gpd/ft. In western parts o region, the coefficient of permeability ranges from

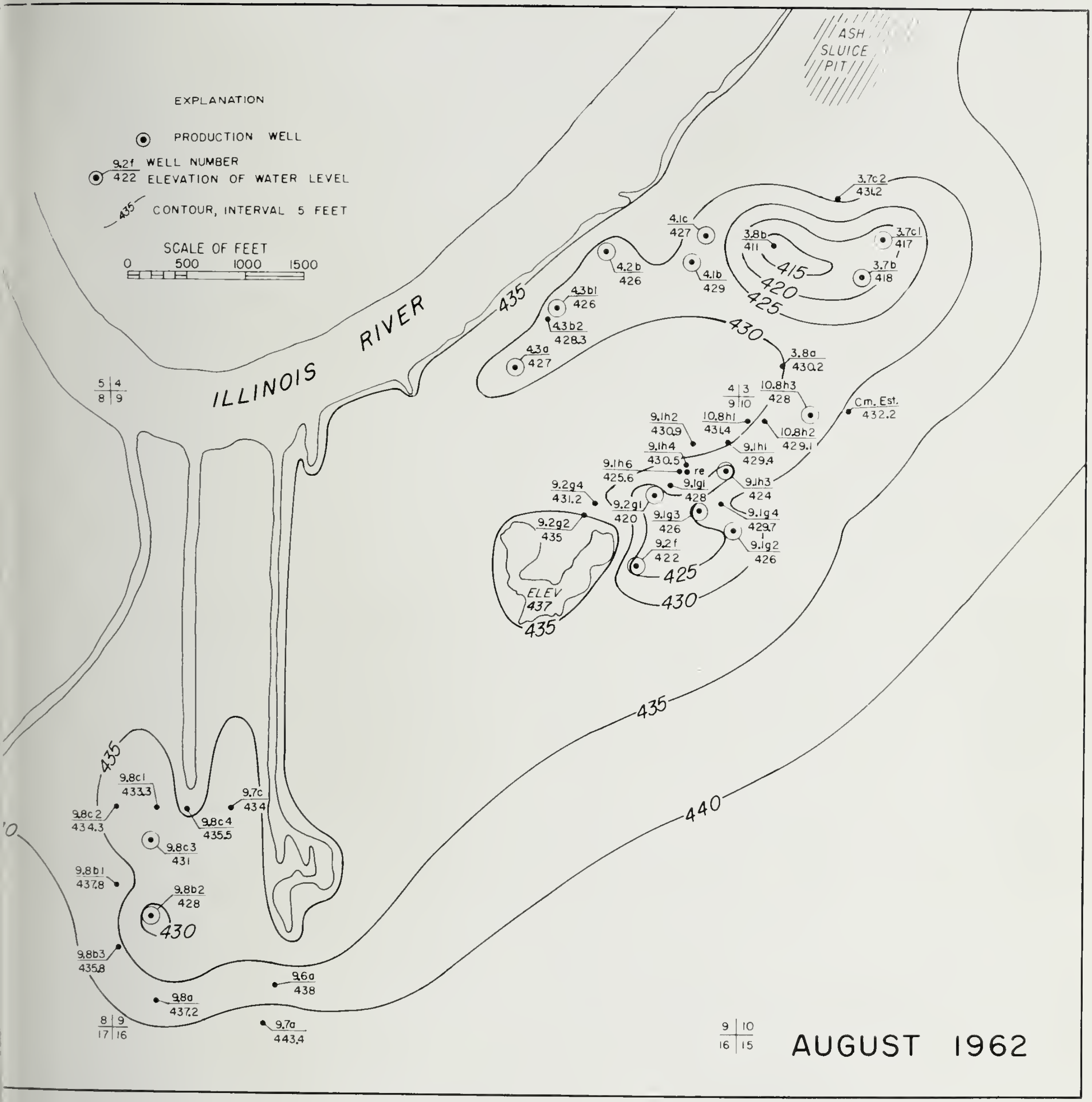


Fig. 26B. Approximate elevation of the water table in the northern part of the Havana region in August 1962.

0 gpd/sq ft and the coefficient of transmissibility
s from 560,000 to 1,250,000 gpd/ft. Most coeffi-
of storage are in the artesian or leaky artesian
. The coefficients of storage were computed from
sults of relatively short-term tests. Longer pump-
ests would give larger coefficients of storage as
y drainage of interstices occurs. For periods of
ing involving several months or more, a coefficient
0 is more realistic than the determined values and
d in this report.

Well-production tests

During the period 1930 to 1962, well-production tests were made by drillers, well owners, and the State Water Survey on 30 wells in the region. The well-production tests consisted of pumping a well at a constant rate and frequently measuring the drawdown in the pumped well. Drawdowns were commonly measured with an airline or electric dropline; rates of pumping were usually measured by means of a circular orifice at the end of the pump discharge pipe.

Table 3. Results of Aquifer and Well-Production Tests

Well number	Depth (ft)	Diameter (in)	Length of screen (ft)	Year of test	Length of test (min)	Pumping rate (gpm)	Drawdown (ft)	Method of analysis*	Observed specific capacity (gpm/ft)	Adjusted specific capacity (gpm/ft)	Saturated thickness of aquifer (ft)	Coefficient of transmissibility (gpd/ft)	Coefficient of permeability (gpm/ft²)	Coeffi of sto
CSS—														
18N12W-14.8h	89	36–16	20	1959	1–250	1000	...	T-D	......	.. ..	80	600,000	7500	0.00
					250	1000	16.7	SC	60	295	80	600,000	7500	......
18N12W-15.2f	86	48–16	25	1956	150	600	3.7	SC	162	305	84	600,000	7200	.....
19N9W-31.7b2	32	36–16	16	1936	1440	154	7.9	SC	20	111	90	220,000	2500	.....
MSN—														
21N6W-4.3g	102	36–16	20	1961	270	700	12.0	SC	58	410	160	820,000	5100	. ...
21N7W-5.7f	128	36–16	40	1962	270	1480	12.3	SC	120	470	170	950,000	5600	......
21N7W-15.7f	112	36–16	52	1962	360	650	3.7	SC	175	482	150	1,000,000	6700	.. ...
21N7W-25.6a	150	6	10	1960	1–60	60	. .	T-D	....	. . . .	125	275,000	2200	0.0
21N7W-25.7a	135	8	15	1960	424	60	1.97	SC	30.5	147	125	310,000	2500	... .
21N8W-28.1g	122	36–16	56	1959	180	1000	4.3	SC	230	400	165	820,000	5000	....
21N8W-36.7b	106	36–16	40	1960	180	1150	10.0	SC	115	450	170	850,000	5000	. ..
22N6W-33.7b	105	36–16	28	1960	120	750	6.3	SC	118	630	165	1,250,000	7600	. ..
22N7W-23.2d	80	36–16	44	1959	180	1735	12.0	SC	144	307	140	560,000	4000	....
22N7W-24.4e	108	36–16	40	1960	180	150	10.0	SC	115	423	160	800,000	5000	.. .
22N7W-27.2c	125	36–16	40	1961	180	1200	12.2	SC	99	382	170	720,000	4200	... .
22N7W-33.8h	136	6	10	1940	60	210	23.0	SC	9.1	344	155	640,000	4100	. ...
22N7W-34.6c	127	36–16	40	1961	240	1225	13.0	SC	95	367	170	700,000	4100	....
23N6W-21.3d	81	10	20	1937	60	120	2.0	SC	60	375	90	800,000	8900	...
TAZ—														
22N4W-16.8a	213	42–18	80	1960	1–360	2250	...	T-D	. .	.. ..	168	275,000	1640	0.0
					540	2250	23.0	SC	98	157	150	310,000	2000	... .
22N4W-16.8b1	212	6	15	1960	350	200	11.1	SC	18	152	166	360,000	2100	. .
22N4W-16.8b2	209	46–16	80	1960	360	2250	25.0	SC	90	165	168	330,000	2000	.
23N5W-26.8a1	115	8	8	1948	60	150	13.4	SC	11.2	104	95	200,000	2200	...
24N5W-9.8b2	99	38–26	20	1930	30	1000	6.7	SC	148	167	33	300,000	9000	.. .
24N5W-9.8b6	67	2	38	1930	1–60	1000		T-D	. . .	. . ..	33	240,000	7300	0.0
24N5W-9.8b1	59	38–25	30	1944	60	2000	14.0	SC	143	163	31	330,000	10000	..
24N5W-9.1g2	88	48–30	20	1950	465	1016	9.0	SC	113	210	44	420,000	9500	..
PEO—														
7N7E-28.6e1	67	8	15	1959	2	430	2.8	SC	150	270	33	500,000	15000	....
7N7E-28.6e2	64	1.25	3	1959	1–10	430	..	T-D	......	......	33	500,000	15000	0.0
7N7E-28.6e2	64	1.25	3	1959	1100	430	.	D-D	. . .	. . . .	. . .	....	. . . .	..
7N7E-28.7e	64	1.25	3	1959	1100	430	..	D-D	. ....	....	33	500,000	15000	..
7N7E-28.8d	64	1.25	3	1959	1100	430		D-D		......	....	....	....	..
7N7E-29.2d1	73	16	20	1960	2	985	18.4	SC	53.5	95	20	150,000	7500	...
					1–500	985	......	T-D	. ..	.....	20	180,000	9000	..
7N7E-29.2d2	73	6	6	1960	1	985	..	D-D	. ...	......	20	182,000	9100	0.0
7N7E-29.2d3	72	6	6	1960	3990	985	. ..	D-D	. ..	......	20	180,000	9000	..
7N7E-29.1d	75	6	6	1960	. . .	. . .			.	....	.. .	.. ..	. ....	.

* T-D = time-drawdown; SC = specific capacity; D-D = distance-drawdown.

Drawdown data were adjusted for the effects of partial penetration with methods described by Butler (1957), the values he gave (table 4), and the following equation:

$$s = C_{pp}\, s_{pp} \qquad (3)$$

where:

s = drawdown for fully penetrating conditions, in ft

C_{pp} = partial penetration constant from table 4

s_{pp} = observed drawdown under partial penetration conditions, in ft

Drawdown data were further adjusted for well loss, which is the head loss or drawdown in the pumped well due to the turbulent flow of water as it enters the well itself and flows upward through the bore hole. Wel may be represented approximately by the followin lationship (Jacob, 1946):

$$s_w = CQ^2$$

where:

s_w = well loss, in ft

C = well-loss constant, in sec²/ft⁵

Q = rate of pumping in cubic feet per second (c

In wells having appreciable well loss, the speci pacity decreases with an increase in the pumping The value of C in equation 4 may be estimated fro

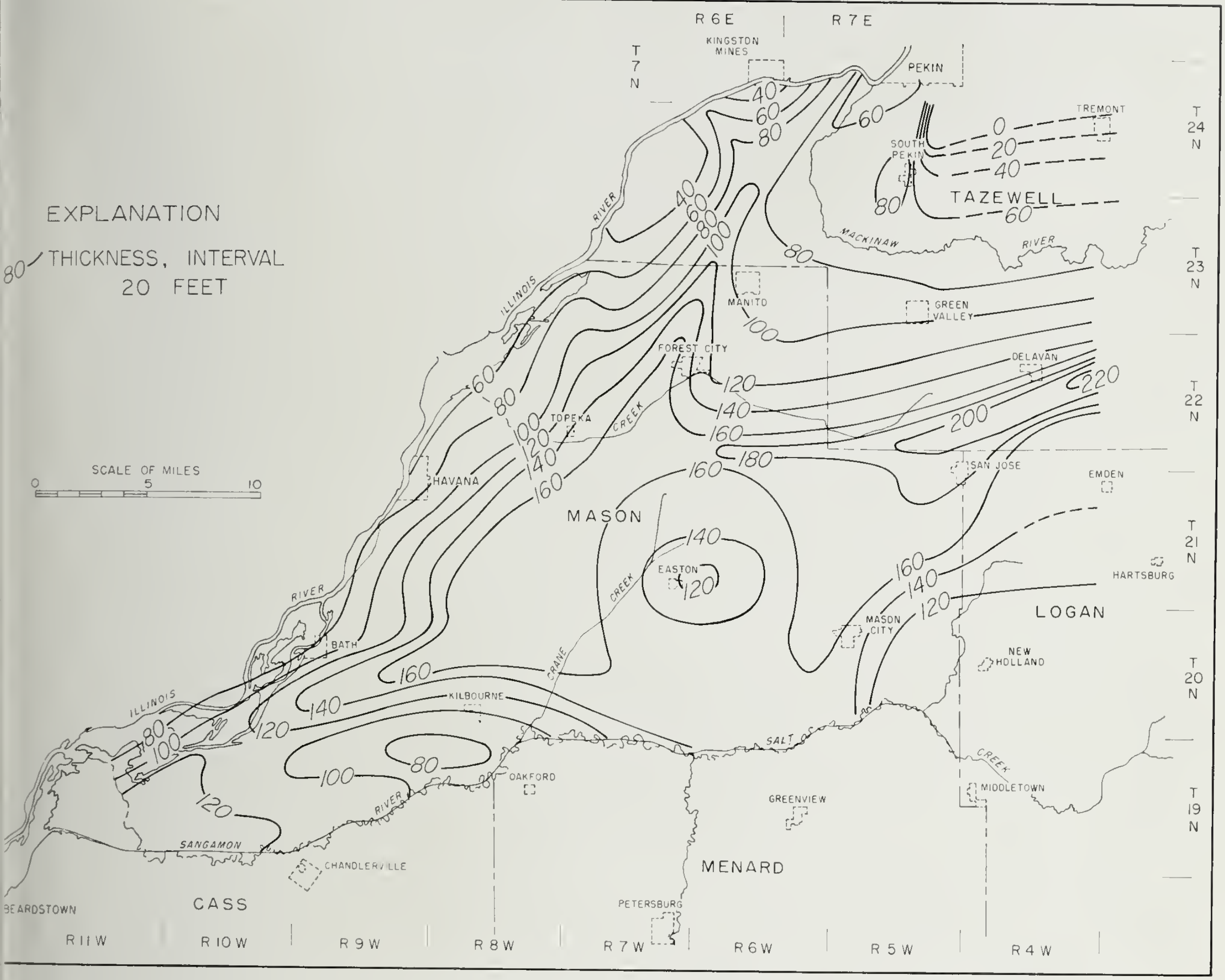


Fig. 27. Saturated thickness of unconsolidated deposits in 1960.

ollected during a ''step-drawdown'' test by using uations given below (Jacob, 1946). During a step-lown test the well is operated during three succes-eriods of 1 hour at constant fractions of full ca-.

teps 1 and 2

$$C = \frac{(\Delta s_2/\Delta Q_2) - (\Delta s_1/\Delta Q_1)}{\Delta Q_1 + \Delta Q_2} \qquad (5)$$

teps 2 and 3

$$C = \frac{(\Delta s_3/\Delta Q_3) - (\Delta s_2/\Delta Q_2)}{\Delta Q_2 + \Delta Q_3} \qquad (6)$$

:

Δs terms represent increments of drawdown pro-ed by each increase (ΔQ) in the rate of pumping. commonly used dimensions of Δs and ΔQ are feet cfs, respectively.

Step-drawdown tests were made on several wells in the region. Data collected during these tests were substituted into equations 5 and 6 to determine well-loss constants. Computed values of C are given in table 5.

Table 4. Values of Partial Penetration Constant for Pumped Well

	a^*			
	0.2	0.3	0.5	0.7
$(r_w/m)\sqrt{P_v/P_h}^*$	Values of C_{pp}			
0.0000	0.200	0.300	0.500	0.700
0.0001	0.221	0.324	0.525	0.719
0.0003	0.236	0.342	0.543	0.732
0.0010	0.266	0.376	0.578	0.759
0.002	0.294	0.408	0.611	0.783
0.003	0.315	0.432	0.636	0.803
0.006	0.363	0.487	0.692	0.846
0.010	0.410	0.541	0.748	0.888

* r_w = nominal radius of well, in ft; m = saturated thickness of aquifer, in ft; a = fractional penetration, length of screen divided by saturated thickness of aquifer; P_h = horizontal permeability of aquifer, in gpd/sq ft; and P_v = vertical permeability of aquifer, in gpd/sq ft.

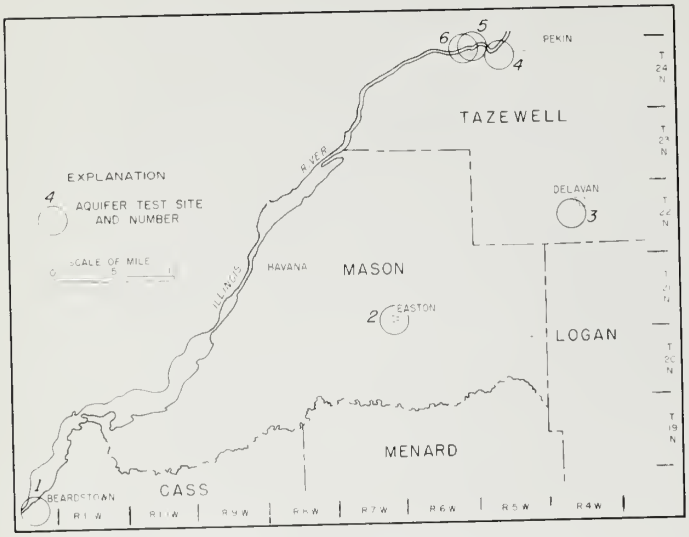


Fig. 28. Location of aquifer test sites.

Values of well loss were estimated, for all wells for which well-production data are available, on the basis of results of the step-drawdown tests, well-construction data, pumping-rate data, and equation 4.

The average coefficient of storage, 0.0004, computed from aquifer-test data and several values of pumping period, t, and radius of a well, r_w, were substituted into the following equation (Walton, 1962) to determine the theoretical relationship between specific capacity and the coefficient of transmissibility for various values of r_w^2/t.

$$Q/s = T/[264 \log (Tt/2693 r_w^2 S) - 65.5] \qquad (7)$$

where:

Q/s = specific capacity, yield of the well in gpm/ft
T = coefficient of transmissibility, in gpd/ft
S = coefficient of storage, fraction
r_w = nominal radius of well, in ft
t = time after pumping started, in min

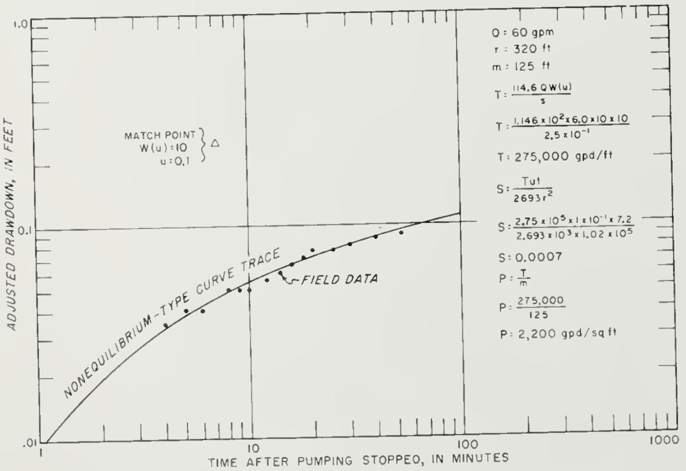


Fig. 29. Time-recovery for well MSN 21N7W-25.6a at Easton.

Table 5. Computed Well-Loss Constants

Well number	Average C (sec^2/ft^5)	Well number	Avera (sec^2/
CSS 18N12W-14.8h	1.7	TAZ 22N4W-16.8b2	0.
CSS 18N12W-15.2f	0.3	TAZ 23N5W-26.8a1	43.
MSN 21N7W-25.7a	0.4	TAZ 24N5W-9.8b5	0.
MSN 22N7W-33.8h	79.0	TAZ 24N5W-9.8b1	0.
MSN 23N6W-21.3d	16.0	TAZ 24N5W-9.1g2	0.
TAZ 22N4W-16.8a	0.2	PEO 7N7E-28.6e1	1.
TAZ 22N4W-16.8b1	10.1	PEO 7N7E-29.2d1	1.

Figure 33 shows the relationship between spe capacity and the coefficient of transmissibility for eral values of r_w^2/t. This graph, specific capacities justed for the effects of partial penetration and loss, and data concerning the lengths of tests and r of wells were used to estimate coefficients of transm bility. Coefficients of transmissibility estimated well-production data are given in table 3.

The results of aquifer and well-production tests available geohydrologic data were used to delin areas of high (area 1) and relatively low (area 2 permeabilities (fig. 34). Area 1 is approximately belt of coarse Wisconsinan outwash, underlain by t Sankoty Sand, paralleling the river. Area 2 is a containing the margins of Wisconsinan outwash, consinan and Illinoian upland, and underlying San and Mahomet Sands. Within area 1 the average cient of permeability of the sand and gravel dep ranges from 15,000 gpd/sq ft in the northern par the region, where very coarse deposits were laid in the narrow gorge, to about 4000 gpd/sq ft in the

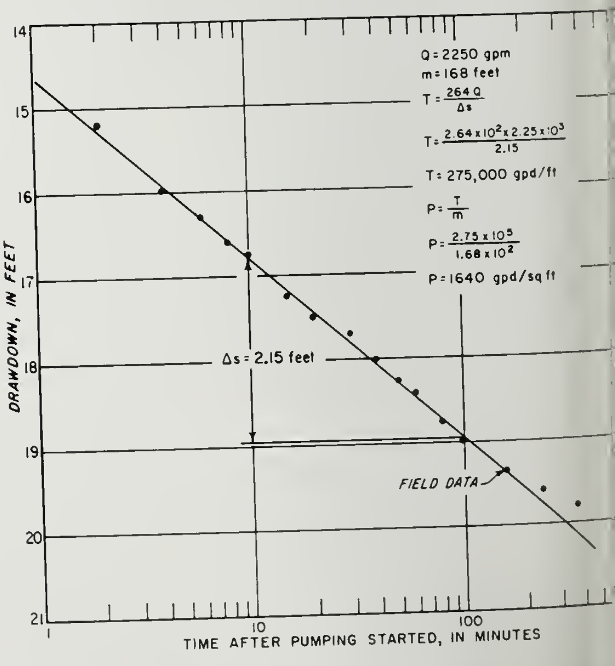
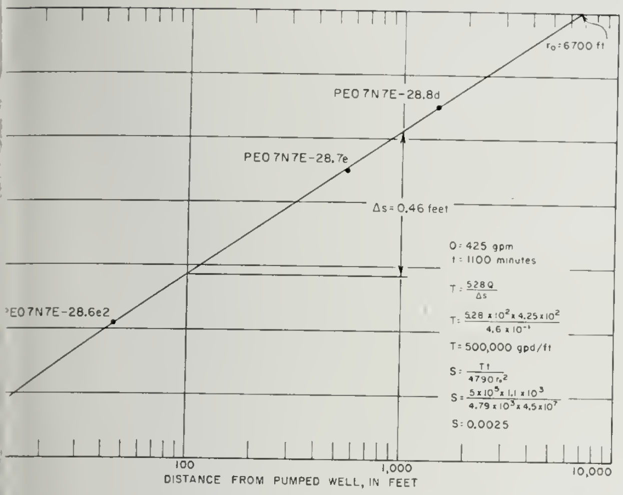
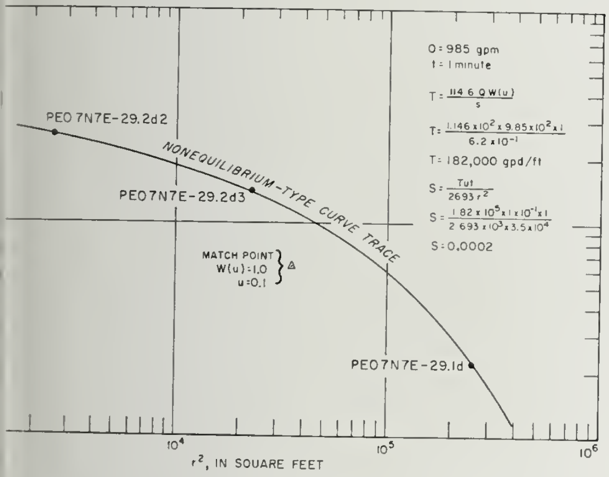


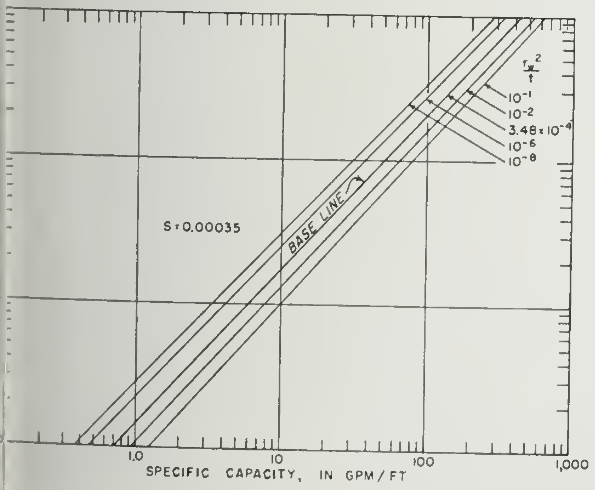
Fig. 30. Time-drawdown for well TAZ 22N4W-16.8a near Dela



I. Distance-drawdown for aquifer test made near Mapleton, October 1959.



. Distance-drawdown for aquifer test made near Mapleton, October 1960.



Coefficient of transmissibility versus specific capacity for several values of well radius and pumping period.

central part. In area 2, the eastern part of the region, the average coefficient of permeability ranges from 2000 to 2500 gpd/sq ft. To estimate the probable coefficient of transmissibility at any site, the coefficient of permeability at the site (fig. 34) is multiplied by the saturated thickness of the aquifer at the site (fig. 27).

Theoretical Effects of Pumping

Pumping from wells in the sand and gravel deposits has a widespread effect on water levels. The nonequilibrium formula, hydraulic properties determined from the results of aquifer and well-production tests, and an estimated long-term storage coefficient were used to evaluate the magnitude of interference between wells and well fields and to compute the theoretical decline in the water table at any distance from a pumped well and after any pumping period.

Figure 35 shows the amounts of interference that will occur at distances of 100 feet to 10 miles from a well pumping continuously at 1000 gpm for periods of 90 days, 180 days, and 1 year in parts of the aquifer (areas 1 and 2 in fig. 34) with coefficients of transmissibility of 800,000 and 300,000 gpd/ft, respectively. The drawdowns given occur at equal distances from the pumped well in all directions. The values of coefficient of transmissibility used in preparing the graphs cover the general range of the hydraulic properties in the Havana region. The graphs assume that all the water pumped is withdrawn from storage and that the aquifer is infinite in areal extent.

The drawdown is appreciable several miles from the pumped well, indicating that even widely spaced wells in the sand and gravel deposits will interfere with one another. For example (fig. 35A), the drawdown at a distance of half a mile is about 0.80 feet for a pumping period of 1 year. The theoretical drawdown is directly proportional to the pumping rate. If the pumping rate is 2000 gpm instead of 1000 gpm the drawdown would be double that shown in figure 35.

Figure 36 shows the amounts of interference that will occur at any time from 0.1 to 100 years at a distance of 1000 feet from a well being pumped continuously at 1000 gpm in the parts of the aquifer (areas 1 and 2, fig. 34) with coefficients of transmissibility of 800,000 and 300,000 gpd/ft, respectively. Again an aquifer infinite in areal extent is assumed.

To show the factors governing the response of the aquifer to pumping, theoretical values of drawdown were computed for a hypothetical well system southeast of Havana.

For this example, it was assumed that two 12-inch radius wells, 180 feet deep and having 40 feet of screen, are developed on a line along State Route 97 and spaced 1000 feet apart about 1.5 miles southwest of Havana. It was assumed also that each well is pumped continuously at a rate of 1000 gpm for 1 year. The total drawdown in feet, s_t, at the end of the 1-year pumping period in well 1 is equal to the drawdown, s_1, due to pumping the well itself, plus the interference, s_2, due to pumping well 2, minus the buildup, s_3, due to the image wells associated with the Illinois River, or

$$s_t = s_1 + s_2 - s_3 \tag{8}$$

The drawdown, s_1, has three components: (1) the drawdown or head loss due to the laminar flow of water in the aquifer towards the well, s_a; (2) the drawdown or head loss (well loss), s_w, resulting from the turbulent flow of water in the aquifer in the immediate vicinity of the well, through the well screen, and in the well casing; and (3) the drawdown or head loss, s_p, resulting from the partial penetration of the pumped well.

The effect of the Illinois River on the drawdown in the well, s_3, is the same as though the aquifer were infinite and as if recharging wells were located across the real boundary, on a line at right angles thereto, and at the same distance from the Illinois River as the real pumping wells.

Equation 1 was used to compute s_a, s_1, and s_3. effective radius equal to the nominal radius, 1 foot, assumed in the computations, as were an average coe- cient of transmissibility of 800,000 gpd/ft and a lo- term coefficient of storage of 0.05. A reasonable e- mate of the value of C for a properly constructed a developed well is 1.0. A C value of 1.0 and equation were used to determine s_w. A (P_h/P_v) ratio of 2.5 assumed in computing s_{pp} with equation 3. The diff- ence between s_{pp} and s_a is equal to s_p.

The drawdown values for s_1, s_2, and s_3 are as follo s_1 equals 11.39 feet (s_a of 3.06 plus s_w of 4.94 plus s_p 3.39); s_2 equals 1.08 feet; and s_3 equals 0.06 feet.

The total drawdown, s_t, in well 1, as the result pumping wells 1 and 2 at rates of 1000 gpm for 1 y is about 12.4 feet. The nonpumping water level in vicinity of the hypothetical well field is about 20 below land surface. The pumping level in well 1 at end of the pumping period thus would be about 32 below the land surface.

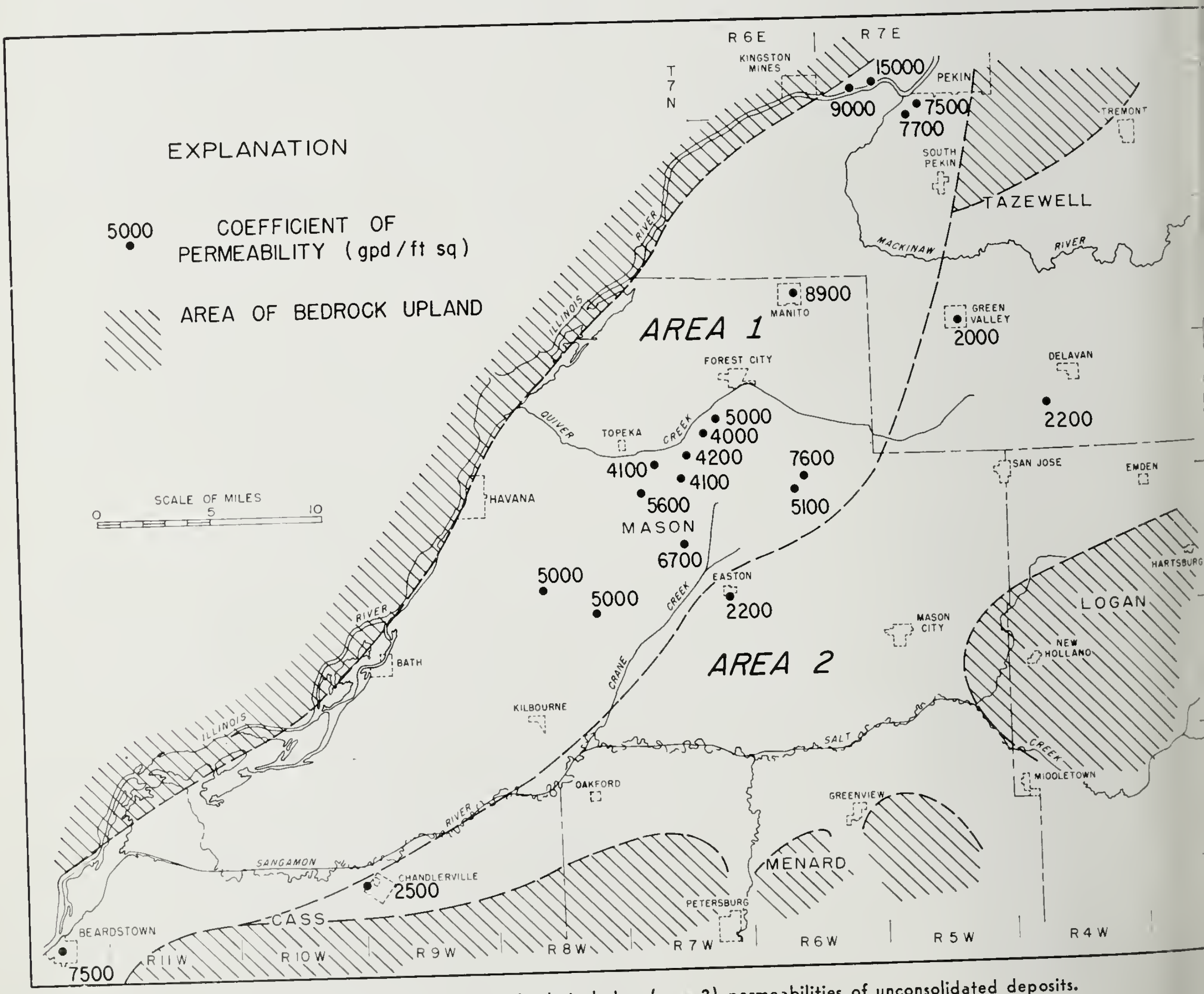
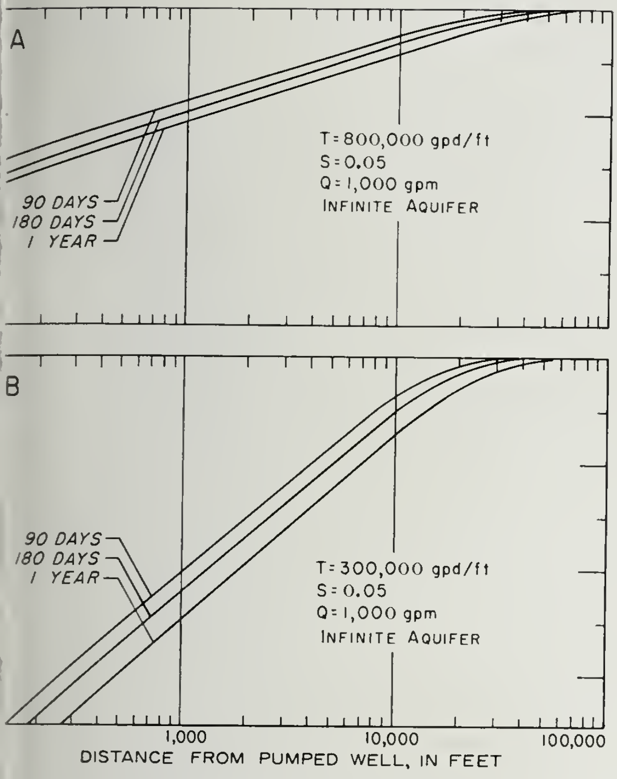


Fig. 34. Areas of high (area 1) and relatively low (area 2) permeabilities of unconsolidated deposits.



. Theoretical distance-drawdown for area 1 (A) and area 2 (B). Area boundaries are shown in figure 34.

hydraulic properties of the aquifer in the vicinity hypothetical well field are not precisely known; ore, the results of computations indicate only der of magnitude of the effects of pumping wells ast of Havana.

Recharge Directly from Precipitation

w lines were drawn at right angles to water-table rs (fig. 25) down-gradient from ground-water ls and ridges to delineate the four flow channels in figure 37. The amounts of recharge directly precipitation minus ground-water evapotranspira- sses to parts of the unconsolidated deposits within w channels are equal to the quantities of water g through flow cross sections A—A′, B—B′, C—C′, —D′. The flow channels are in the areas where ter table is below plant feeding depth and ground- evapotranspiration losses and storage changes are therefore, for practical purposes recharge is to the quantities of water moving through flow sections. Flow through cross sections A—A′, , C—C′, and D—D′ was computed to be about 1.7, 2, and 2.0 mgd, respectively, with the following f Darcy's law:

$$Q = TIL \qquad (9)$$

:

quantity of water percolating through a given flow cross section, in gpd

T = coefficient of transmissibility, in gpd/ft
I = hydraulic gradient of water table at flow cross section, in ft/mi
L = length of flow cross section, in mi

Recharge rates were estimated as the quotients of flow through cross sections and surface areas of flow channels. Areas of flow channels 1, 2, 3, and 4 are 6.6, 7.7, 6.4, and 4.2 square miles, respectively. Recharge rates average about 270,000 gpd/sq mi in flow channels 2 and 3 and about 490,000 gpd/sq mi in flow channels 1 and 4. Flow channels 2 and 3 lie in areas where layers of Illinoian till overlie the aquifer and retard the vertical movement of water. Flow channels 1 and 4 lie in areas where fairly coarse-grained sand and gravel deposits occur from the surface down to bedrock.

Pumpage

Pumpage-use data are classified in this report according to the four main categories used by the U.S. Bureau of the Census. These are (1) public, (2) industrial, (3) rural nonirrigation, and (4) irrigation. Most water-supply systems furnish water for several types of use. In all cases, the total pumpage may be known approximately, but the final use of the water cannot always be determined. Any water pumped by a municipality is called a public supply, regardless of the use of water; any water pumped by an industry is called an industrial supply, regardless of the use of the water. Rural nonirrigation supplies provide water for domestic and stock use on farms and individual residences and may include water for irrigating lawns and home gardens. Irriga-

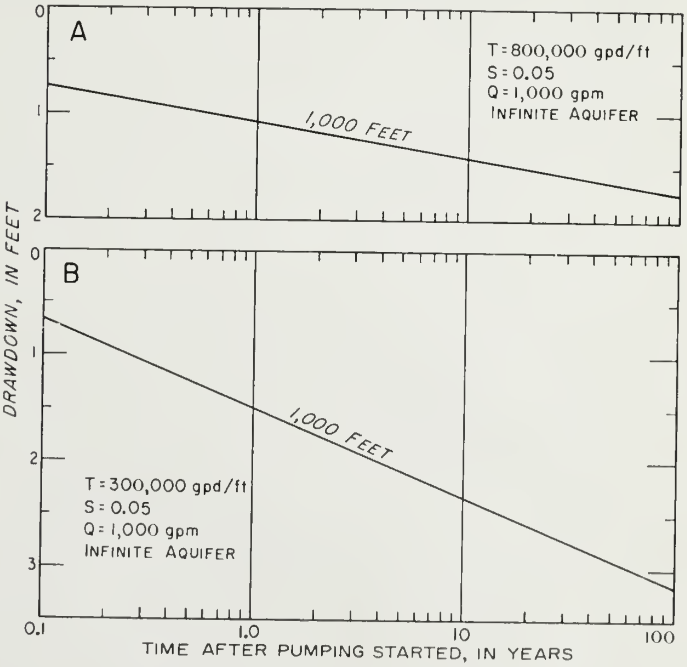


Fig. 36. Theoretical time-drawdown for area 1 (A) and area 2 (B). Area boundaries are shown in figure 34.

tion water is that which is applied to the land to supplement natural soil moisture for growing crops.

Public pumpage shows a gradual change with seasons, the average winter use being about three-fourths of the average summer use. Industrial wells generally have the most uniform pumpage during the year unless air-conditioning installations are used or the industry is seasonal. However, if a change in operation occurs, as during strikes or vacation shut-downs, the variation in pumpage is radical or sudden. Pumpage for irrigation is seasonal and varies considerably from year to year, depending on weather conditions.

The reliability of pumpage data varies greatly. Municipal pumpage is nearly always metered in cities, but many smaller villages operate without meters. Only a small part of the industrial supply is metered. Pumpage data from municipalities and the larger industrial establishments are systematically recorded. The pumpage from farm wells and from the many individual residential wells is estimated on the basis of detailed use surveys of a few selected sections considered typic Irrigation wells nearly always operate without mete For these reasons it is difficult to ascertain exact pum age figures.

Table 6. Estimated Pumpage in the Havana Region in 1960, Subdivided by Use

Type of use	Total pumpage (*mgd*)
Industrial	18.32
Municipal	2.44
Rural nonirrigation	0.50
Irrigation	0.09
Total	21.35

Total ground-water pumpage in the Havana regi in 1960 was about 21 mgd. Of this amount, appro mately 85 percent was pumped for industrial use the extreme northern part of the region; the remaini 15 percent was withdrawn largely by municipalit (table 6). Graphs of estimated municipal and industr

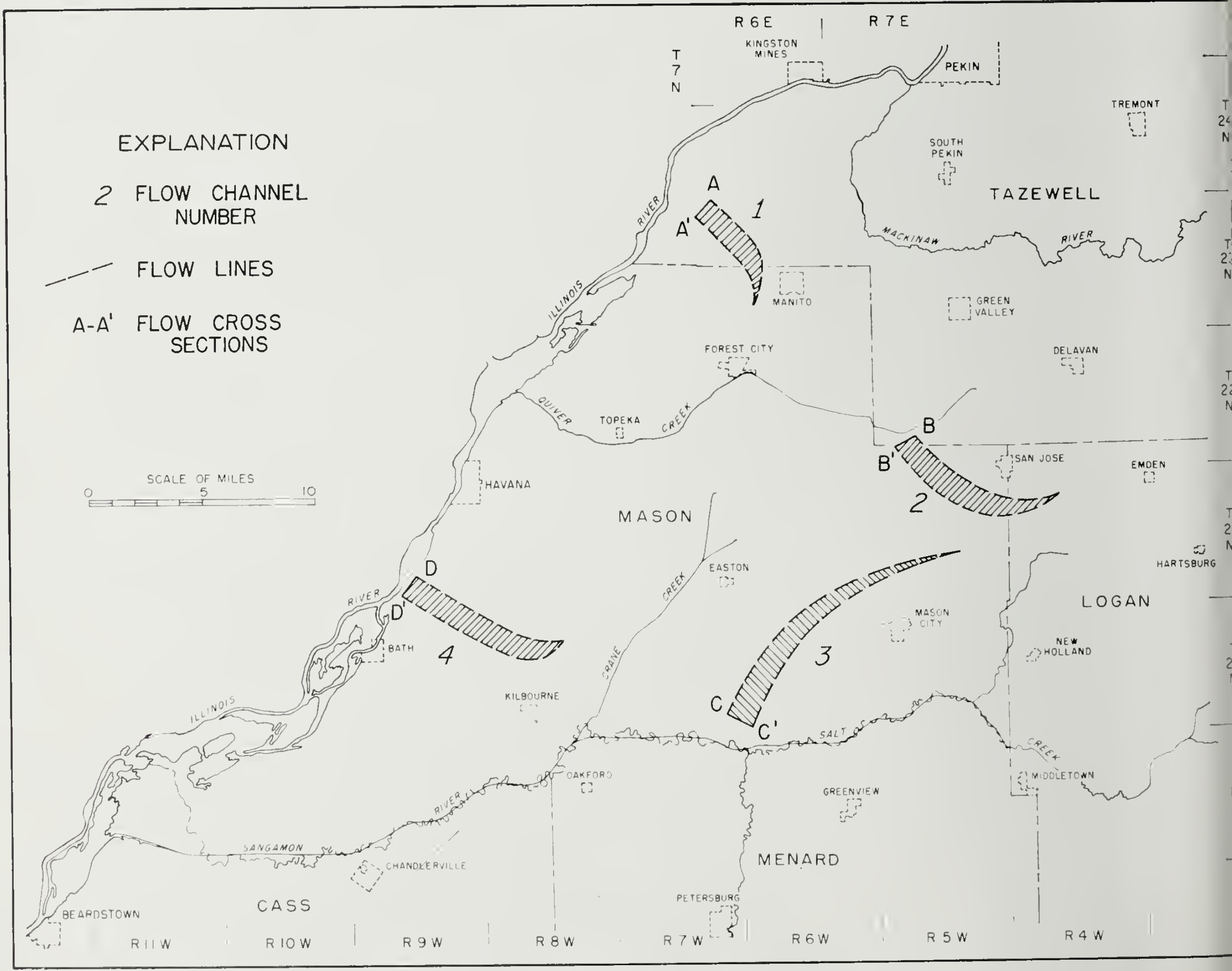


Fig. 37. Location of flow channels used to determine recharge rates.

ıpage for the period of record in the northern, cen- , and southern parts of the region are given in re 38.

:unicipal pumpage has gradually increased as per ta use has increased with the introduction of auto- ic washing machines, dishwashers, and garbage dis- ıl units into the average home. Major fluctuations pumpage are due to large changes in industrial ıpage. The increase in pumpage in the central part he region in 1947 (fig. 38) reflects the increase in ınd-water use by the Illinois Power Company plant Iavana, which was placed in operation during that ·; the reduction in pumpage after 1952 was caused ı decrease in ground-water use by that plant. The ıpage graph for the northern part of the area re- s changes in pumpage within the industrial complex h of Pekin.

ural nonirrigation pumpage was estimated on the s of data in the 1950 and 1960 reports of the U.S. eau of the Census and on a per capita consumption ıe of 50 gpd. Total rural nonirrigation pumpage about 500,000 gpd in 1960.

urveys of the extent of supplemental irrigation de- pment and the total yearly pumpage for supple- tal irrigation were made in 1957 and 1959 by the artment of Agricultural Economics, University of ıois, in cooperation with the Agricultural Research vice, U.S. Department of Agriculture (Davis, 1960; is and Jansen, 1960). Data on supplemental irriga- pumpage gathered during these surveys and addi- al data furnished by Ray Lane, Soil Conservation vice, U.S. Department of Agriculture, are used in report.

ı 1960 there were 14 known supplemental irrigation ems within the Havana region, all located in Mason nty. Of this total, 11 systems used ground water, sed surface water, and 1 used a combination of ınd and surface water as sources of supply.

plemental irrigation

lthough annual rainfall generally is sufficient to port sustained production of crops and pasture in region, short periods of drought are common, and plemental irrigation is used to stabilize annual yields. irrigated acreage has increased in recent years ·ely because of the availability of an adequate supply ;ood ground water for irrigation. Other factors that e encouraged supplemental irrigation are the occur- ·e of sandy textured soils that have little water- ling capacity; improvements in irrigation equip- ıt, particularly portable, lightweight pipe and ınklers; the desire for increased yields and crops of ıer quality; and the proximity of city markets for ·k crops. Only in recent years have farmers in ·ral come to realize the full potentialities of supple- ıtal irrigation. Information, including costs, is given yearbooks of the U. S. Department of Agriculture 55, 1957).

Data on supplemental irrigation from ground-water sources in the Havana region are summarized in table 7. The number of irrigation systems and total acres irrigated increased in 1960; however, total ground-water withdrawals for supplemental irrigation decreased because of an abundance of precipitation during the growing season of that year. The correlation between total

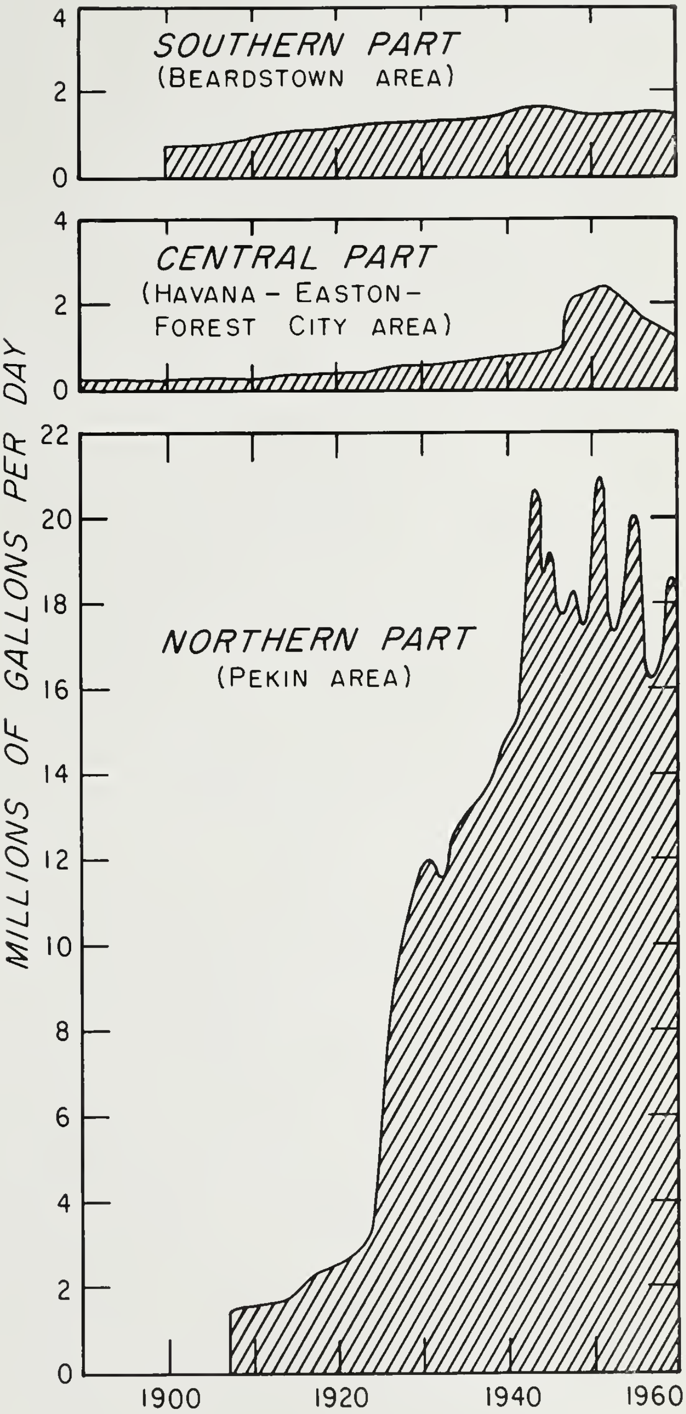


Fig. 38. Estimated municipal and industrial pumpage, 1890-1960, in the Havana region.

Table 7. Supplemental Irrigation from Ground-Water Sources in the Havana Region

Year	Number of irrigation systems	Acres irrigated	Annual pumpage (*mil gal*)	Precipitation during growing season (*in*) Total	Departure from normal
1954	4	130	14.7	13.17	+2.32
1955	5	330	33.7	12.35	+1.50
1956	5	190	14.5	19.97	+2.12
1959	6	340	59.1	6.07	−4.75
1960	11	530	32.2	17.78	+6.96

pumpage and precipitation during the growing season is apparent. The large rate of increase in the number of irrigation systems between 1959 and 1960 was caused by drought conditions and unfavorable rainfall distribution during the summer of 1959, which had resulted in poor crop production and heavy losses in income. Currently, sprinkler irrigation systems are used almost exclusively for supplemental irrigation.

Farm crops most likely to receive supplemental irrigation in the Havana region are (1) alfalfa; (2) corn, wheat, and other grains; (3) pasture; and (4) potatoes and other vegetables. Approximate moisture requirements of these crops for moderate climatic conditions, such as are found in Illinois, were compiled by the U. S. Bureau of Reclamation (1951) and are given in table 8.

Table 8. Moisture Requirements of Selected Crops

Crop	Daily moisture demand per acre (*in*)	Irrigation capacity requirements *gpm/acre*	*gpd/acre*
Alfalfa	0.20	5.4	7800
Grain	0.20	5.4	7800
Pasture	0.16	4.3	6200
Potatoes	0.12	3.3	4750

Also given is a tabulation of the water required per acre for these crops with an irrigation system operating at a field efficiency of 70 percent. Alfalfa and grain crops use approximately one-fifth of an inch of water per acre per day, whereas pasture and potatoes require slightly over one-sixth to one-eighth of an inch of water per acre per day, respectively. An irrigation system designed on the basis of a maximum crop demand of one-fifth of an inch per acre per day must be capable of producing 5.4 gpm per acre continuously during drought periods to satisfy the moisture requirements of the crop.

The primary factor controlling the rate of water application per acre is the infiltration capacity of the soil. The infiltration capacity of the various soil types commonly found in the region are assumed to be comparable to infiltration capacities determined by the U. S. Bureau of Reclamation (1951) for soils of the western states. These capacities are given in table 9.

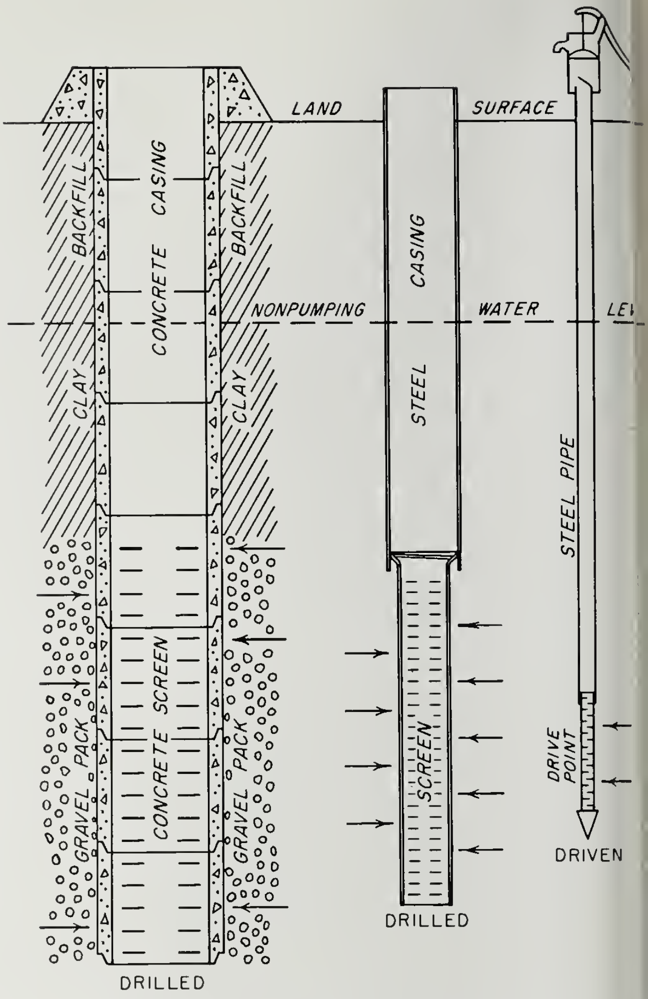


Fig. 39. Construction features of drilled and driven wells.

Sand and sandy loam soils predominate in the region, and table 9 indicates that the infiltration capacities of these soils are about 2 and 1 inches per hour (54 a 27 gpm), respectively. On the basis of these values a pumping rates of 500 and 1000 gpm per irrigation w the maximum number of acres that can be irrigated one well ranges from 11 to 19 in sandy soil and fr 22 to about 37 in sandy loam soil. The irrigation ti required to meet daily peak moisture requirements alfalfa and grain on these acreages would be about and 1.5 hours for sand and sandy loam soils, respective

Construction Features of Wells

Wells may be classified according to the method construction used in drilling the hole and inserting t screen; the two types commonly found in the Hava

Table 9. Infiltration Capacity of Soils

Soil type	Infiltration capacity *in/hr*	*gpm**
Sand	2	54
Sandy loam	1	27
Loam	0.5	18.5
Silt and clay loam	0.2	5.4

* 70 percent irrigation efficiency.

on are drilled and driven wells. A few dug and d wells still exist, but these methods of well con- ction are rarely used today. The drilled wells may further classified as to method of completion— ral pack or artificial pack. Natural coarse materials ounding the well are developed in the natural pack ; materials having a coarser, more uniform grain than the natural formation are added around the en of the artificial pack well.

rilled wells (fig. 39) in the Havana region may be d with either concrete or steel casing. If concrete ng is used, the well screen is generally made of orated sections of the same material; steel casing s may be equipped with a section of slotted pipe, commercial well screen made of stainless steel, red s, or other relatively noncorrosive metal. Driven s (fig. 39) are generally cased with black or galva- d pipe 1 to 3 inches in diameter and equipped with 10 feet of commercial wellpoint screen.

he driven well is, by far, the most common type of used for domestic and stock water purposes in most he Havana region because the water table is near surface and is overlain by materials easily pene- ed by a drivepoint. Relatively high yields are ob- ed from small-diameter wells penetrating only the er few feet of the aquifer, the method of construction mple, and the cost is low. This type of well is not tical on uplands along the eastern edge of the on, however, because of the difficulty encountered riving the well deep enough to intersect the aquifer, h lies more than 100 feet below the land surface. ere the depth to water is more than about 50 feet, led wells 4 to 6 inches in diameter are usually con- cted to obtain water for domestic and agricultural

rilled wells are commonly constructed to obtain large ntities of water for municipal, industrial, and irri- on purposes. Records of large-capacity wells in the on are given in table B in the appendix.

ase histories of many large-capacity wells revealed apid decline in well yield, often resulting in costly repairs and even well abandonment, after only a months of operation. This rapid deterioration in yield can be directly traced to overpumping in ny of the wells. Overpumping in this instance refers umping rates high enough to induce the migration ine-grained material from the aquifer toward the face, thereby lowering the permeability of the ifer in the immediate vicinity of the well to the nt that well yields are greatly reduced. In some s the entrance of fine sand through the well screen mes excessive. It is important that wells be prop- designed to prevent entrance of fine material into s and that pumping rates be limited to those that not cause rapid deterioration in yield. Well design eria were given by Walton (1962).

he spacing of production wells is frequently a prob- . The farther apart wells are spaced the less their mutual interference but the greater the cost of connecting pipeline and electrical equipment. The spacing of wells is often dictated by practical considerations such as property boundaries and existing distribution-pipe networks. This discussion is concerned only with the influence of aquifer characteristics and economics on the spacing of production wells.

Theis (1957) derived the following equation for determining the optimum well spacing in the simple case of two wells pumping at the same rate from a thick and areally extensive aquifer:

$$r_s = 2.4\times10^8 c_p Q^2/kT \qquad (10)$$

where:

r_s = optimum well spacing, in ft

c_p = cost to raise a gallon of water 1 foot, consisting largely of power charges but also properly including some additional charges on the equipment, in dollars (1 gal lifted 1 ft = 3.15×10^{-6} kwh)

k = capitalized cost for maintenance, depreciation, original cost of pipeline, etc., in dollars per year per foot of intervening distance

Q = pumping rate of each well, in gpm

T = coefficient of transmissibility, in gpd/ft

In aquifers 100 or less feet thick, it is generally advisable to separate production wells by a distance at least equal to twice the thickness of the aquifer, to minimize the effects of partial penetration. Experience has shown that in the case of a multiple well system consisting of more than two wells the proper spacing between wells is at least 250 feet.

Quality

Typical analyses of ground water are given in table 10. Ground water in the unconsolidated deposits varies in quality from place to place but is of much better quality than water in the Pennsylvanian and Mississippian rocks. Water in Devonian, Silurian, Ordovician (table 11), and older rocks is too highly mineralized for most purposes.

Temperature

Ground-water temperatures have been measured periodically for several years in production wells located in the pumping center south of Pekin. Additional temperature measurements have been made in production wells throughout the region at the time of collection of water samples for chemical analyses. Measured temperatures of well water are included in table 10 and in figure 40.

In the deeper parts of the aquifer away from the Illinois River, the ground-water temperature generally

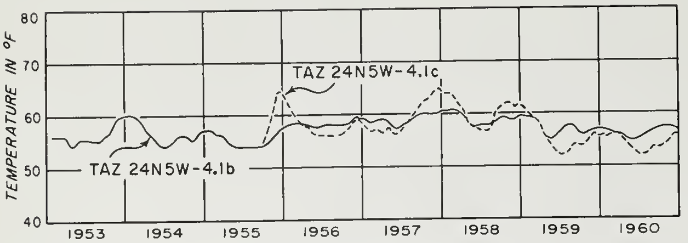


Fig. 40. Ground-water temperatures in selected wells near Pekin, 1953-1960.

ranges between 53° F and 57° F, with an average of 55° F. In the shallower parts of the aquifers near the Illinois River, however, ground-water temperature may vary during the year from a low of about 50° F to a high of about 68° F because of infiltration of warmer or colder surface water.

Surface water entering the aquifer ranges in temperature from 32° F to 85° F. Because of the heat exchange with the sand and gravel under the bed of the river, and a blending of surface water with cooler ground water recharged from rainfall, the range in ground-water temperatures is not so great as the range surface-water temperatures. The changes in grou water temperature in a well a few hundred feet fr the river's edge may lag behind temperature chan in surface water by as much as 8 months because the slow movement of water through the aquifer.

The primary factors that control the time lag a range in ground-water temperature are (1) tempe ture of the surface water, (2) distance of product wells from the river, (3) spacing of production we (4) pumping rates, and (5) amount and temperat of ground-water flow from the land side. In wells cated at or near the river's edge, the water pump from production wells often consists of a high p centage of surface water that enters the aquifer in immediate vicinity of the pumped well; therefore, th is a wide range in the temperature of the ground wat Production wells located farther landward, howev receive a large percentage of ground water of nea uniform temperature recharged by precipitation an smaller percentage of surface water; therefore, range in these ground-water temperatures is small.

Table 10. Chemical Analyses and Temperature of Water in Wells in Unconsolidated Deposits

(Chemical constituents in parts per million)

Well number	Owner*	Depth (ft)	Temperature (°F)	Iron (Fe)	Fluoride (F)	Boron (B)	Silica (SiO$_2$)	Chloride (Cl)	Sulfate (SO$_4$)	Nitrate (NO$_3$)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Alkalinity (bicarbonate) (as CaCO$_3$)	Hardness	Tot disso mine
CSS—																
18N12W-14.8h	Beardstown (C)	89	....	0.6	0.2	0.3	16.3	39.0	123.6	1.2	97.4	35.0	26.0	260.0	388.0	512.
LOG—																
20N4W-18.1b	New Holland (V)	74	55	0.3	0.0	...	30.2	33.0	135.8	66.0	129.4	59.6	14.2	360.0	569.0	708
21N4W-26.7h	Scully Estate	30		1.5	...		15.0	1.0	2.1	2.2	99.2	39.9	7.6	436.0	412	433.
MSN—																
19N11W-13.7b	Wild Wing Land Co.	93		0.8			15.0	2.0	18.5	1.1	57.7	21.4	6.2	200.0	232.0	244.
20N5W-8.8f1	Mason City (C)	198		0.8			16.8	4.0	2.0	0.9	63.5	27.9	7.8	280.0	273	299.
20N5W-12.2a	E. M. Douglas	90		5.5			13.0	15.0	41.3	3.2	136.6	44.8	10.1	482	525.5	553.
20N5W-22.2a	A. D. Black Estate	145		0.3		...	14.0	2.0	9.7	13.3	71.4	37.0	6.7	322	331	347.
20N8W-2.4e	Ted Kruse	130	55	2.6		0.1	.....	1.0	30.4	2.4	59.2	17.5	1.6	188	220	261.
20N9W-8.4d	L. F. Connolly	63	56	Tr		0.0		0.0	30.9	3.0	27.4	9.8	3.0	80.0	109	143
21N5W-1.1h1	San Jose (V)	101	....	1.0		....	14.5	23.0	82.1	33.2	96.1	41.4	8.1	282	409.5	467.
21N5W-8.1h	R. M. Ainsworth	105	....	0.1	...	....	14.0	6.0	17.1	32.8	86.4	36.4	9.7	334	365.5	392.
21N5W-32.1g	Howard Stone	100	....	0.2			13.0	10.0	19.6	66.4	85.7	42.5	9.4	300	389	410
21N6W-16.1b	L. G. Keisling	54	....	1.6		...	10.0	3.0	28.0	1.3	69.0	22.1	3.7	238.0	264.0	279.
21N7W-5.8f	C. H. Zurburg	63		0.1			6.0	0.0	26.9	1.5	29.0	8.2	3.0	84.0	107.0	124.
21N7W-15.3f	Burnell Steinhauer	119	55	6.9		0.0		1.0	36.4	1.3	73.6	22.4	2.3	240	276	313
21N7W-25.7a	Easton (V)	135	55	2.1	0.2	0.1	18.0	1.0	24.1	1.0	63.1	28.2	3.0	252	274	284
21N7W-30.3f	E. C. Ringhouse	105		0.2	...	0.0		2.0	39.6					144	179	194
21N8W-7.7h	Camp Dreier, D-5	75		0.3		....	12.0	0.0	17.7	4.0	36.5	14.3	6.9	124.0	150.5	169
21N9W-1.2f	Havana (C)	125		0.4	0.1	...	19.3	3.0	24.7	0.2	44.9	15.6	Tr	152.0	177	197
22N6W-2.6h	Nicholas Graff	43		0.1	...		8.0	9.0	48.6	33.6	73.0	29.3	0.5	214.0	303	330
22N6W-29.4a	G. A. Barnes	40		0.1	...	...	...	2.0	38.7					134	153.8	185
22N7W-3.1h	Mason State Forest	31	54	Tr		0.0		1.0	26.7	2.1	40.9	14.0	3.0	136	160	180
22N7W-33.8h	Mason State Tree Nursery	136	...	5.7			28.0	0.0	2.3	0.9	74.3	23.5	2.1	286	284.5	308
22N8W-10.8b	U. S. Dept. of Agr.	62		0.16			13.5	1.0	21.2	18.6	47.6	18.3	1.8	160	194.5	218
23N6W-21.3d	Manito (V)	82	59	1.1	0.2	0.0	13.0	4.0	63.4	3.4	64.4	22.9	5.0	192	255	320
23N6W-24.8e	John Meeker	35	...	2.5		...	9.0	6.0	103	1.7	98.8	29.5	8.3	270	368	419
TAZ—																
22N4W-10.7d1	Delavan (C)	160	54.5	2.0	0.2	...	25.9	2.0	0.0	0.8	77.6	29.6	2.5	320	314	331
22N4W-16.8b2	Hiram Walker & Sons, Inc.	209	55	1.3		0.0		1.0	9.5	1.6	70.4	31.1	Tr	308	304	329
23N5W-26.8a1	Green Valley (V)	115	56	1.8	0.1	0.1	17.5	5.0	44.4	1.0	77.8	32.6	6.0	288	329	382
23N7W-1.5a	Star School	93		10.0	...	...	14.0	7.0	40.7	9.7	45.2	16.0	5.1	130	179	216
23N7W-8.1a	Camp Isaac Walton	90	...	0.0	...	...	14.0	0.0	33.6	8.0	39.8	12.0	7.4	130	167	190
24N5W-9.8c2	Commonwealth Edison Co.	58	...	0.1			8.0	8.0	45.1	10.6	65.2	26.3	11.7	216	271	307
24N5W-34.4h1	South Pekin (V)	90	...	0.1			16.5	14.0	152.5	6.6	86.0	35.9	17.9	218	362	460
24N7W-13.5b	Lawrence Thomas	17		3.6			13.0	12.0	94.1	4.0	90.3	41.3	2.5	284	396	425

* (C) = city owned; (V) = village owned.

e 11. Chemical Analyses of Water Typical for the Glenwood-St. Peter Sandstone (Ordovician)

ple of water collected April 26, 1961, from well MSN 22N8W-31.8e, . White-Hahn; near Havana, Mason County. Location: NW cor. ¼ sec. 31, T.22N., R.8W. Depth: 1442 ft. Lowest formation trated: Glenwood-St. Peter Sandstone.

Laboratory No. 154713

	ppm	*epm*
bidity	26	
r	0	
r	0	
(Fe) (total)	6.8	
ride (F)	3.6	
ride (Cl)	540	15.23
ate (SO_4)	791	16.47
alinity (as $CaCO_3$)	232	4.64
dness (as $CaCO_3$)	504	10.08
l dissolved minerals	2277	

ple of water collected April 26, 1961, from well MSN 23N6W-31.3c, Joseph P. Sparks; Manito, Mason County. Location: 350'N and W of SE cor. NW ¼ SE ¼ sec. 31, T.23N., R.6W. Depth: 1806 ft. est formation penetrated: Glenwood-St. Peter Sandstone.

Laboratory No. 154712

	ppm	*epm*
bidity	24	
r	0	
r	0	
(Fe) (total)	6.6	
ride (F)	2.6	
ride (Cl)	410	11.56
ate (SO_4)	1004	20.89
alinity (as $CaCO_3$)	224	4.48
dness (as $CaCO_3$)	580	11.60
al dissolved minerals	2361	

emical character

The chemical character of the ground water in the vana region is shown by the analyses of samples from wells (table 10). The constituents listed in the table given in ionic form in parts per million; the major stituents, expressed in equivalents per million, are wn graphically in figure 41. Most waters from unsolidated deposits contain less than 500 ppm of solved minerals. Dissolved minerals range from 125 708 ppm and average 297 ppm.

Waters from sand and gravel wells are essentially arbonate waters having an alkalinity greater than hardness and almost equal to the total mineral cont. More than half of these samples contained more n 0.3 ppm iron, with a median of 0.7 ppm and a ximum of 10 ppm. The hardness ranges from 107 569 ppm with a median of 274 ppm. The chloride ntent ranges from 0 to 39 ppm with a median of 3 m. The sulfate content ranges from 0 to 152 ppm l averages 48.8 ppm.

In heavily pumped areas adjacent to the Illinois ver, where the water table has been lowered below stream level, the ground water is a blend of water recharged to the aquifer directly from precipitation and by the induced infiltration of surface water. Such water is generally of better quality than that from unconsolidated deposits in the proximity of the bedrock valley walls.

The chemical composition of the water from bedrock wells is very different from that of the water generally found in the sand and gravel. Table 11 gives analyses of water from two deep bedrock wells obtaining water from the Glenwood-St. Peter Sandstone. Water from the bedrock is much more highly mineralized than water from unconsolidated deposits.

According to classifications given by the U. S. Salinity Laboratory (1954), ground water in the study area is generally excellent to good for irrigation purposes. For all the water sampled, the highly permeable sandy soils of this region provide adequate leaching to prevent the accumulation of harmful salts derived from supplemental irrigation. No boron concentrations above 0.3 ppm were found, and the sodium absorption ratio was always well below a hazardous level.

Potential Yield of Unconsolidated Deposits

A study of the water-yielding characteristics, recharge from precipitation, and the relation between ground-water levels and the Illinois River indicates that the potential yield of unconsolidated deposits in the Havana region is large. The potential yield is here defined as the amount of ground water that can be continuously withdrawn from a reasonable number of wells without creating critically low water levels or exceeding the recharge rate.

The amount of recharge directly from precipitation was estimated to be about 300 mgd. The estimate was based on data from geologic maps and on recharge rates determined from flow-net analysis of the water-table map. If ground-water levels were lowered below the water surface of the Illinois River by pumping from wells adjacent to the stream, recharge by influent seepage of surface water would result. The amount of recharge by induced infiltration depends largely on the permeability of the stream bed and the underlying aquifer, the surface water temperature, the depth of water in the river, and the width of the stream bed. Potential recharge from induced infiltration of surface water cannot be estimated in the absence of specific data on the permeability of the bed of the Illinois River. However, based on studies made in the East St. Louis area (Schicht and Jones, 1962) it is not unreasonable to believe that as much as 50 mgd of surface water could be induced to flow into the unconsolidated deposits under heavy pumping conditions.

A study of the water-yielding character of the unconsolidated deposits (see Hydraulic Properties of Aquifers) indicates that on a gross basis these aquifers, if properly developed, are capable of yielding far more water to wells than will be recharged under heavy pumping conditions. Thus, the potential yield depends upon recharge rates rather than on the water-yielding character of the aquifer. Available data on the specific capacities of existing production wells and hydraulic properties of aquifers were used to determine the probable number of wells needed for full development of the potential yield. It is estimated that, on the average, one well must be in service for each 1 mgd of ground water withdrawn. This figure includes necessary standby wells. If the potential yield is 350 mgd, about 350 wells would be required to produce the amount of ground water available.

Probable consequences of development

Some insight into the probable consequences of developing large quantities of ground water in the Havana region can be gained by reference to ground-water conditions in the East St. Louis area. The East St. Louis area is in southwestern Illinois, encompasses the ma
cities of East St. Louis, Granite City, and Wood Ri
and extends along the valley lowlands of the Mississi
River from the city of Alton south to the village f
Dupo. The area covers about 175 square miles and
approximately 30 miles long and 11 miles wide at
widest point.

As in the Havana region, the aquifer consists of sa
and gravel deposits and is underlain by Mississipp
and Pennsylvanian rocks. The unconsolidated depo
have an average thickness of 120 feet and range
thickness from a feather edge, near the bluff bounda
of the area, to more than 170 feet near the city of W
River. The thickness of the sand and gravel depos
is generally greatest and exceeds 120 feet near
center of a buried bedrock valley that bisects the ar

The coefficient of transmissibility of the uncons
dated deposits commonly exceeds 150,000 gpd/ft a
in the Monsanto, East St. Louis, National City, a

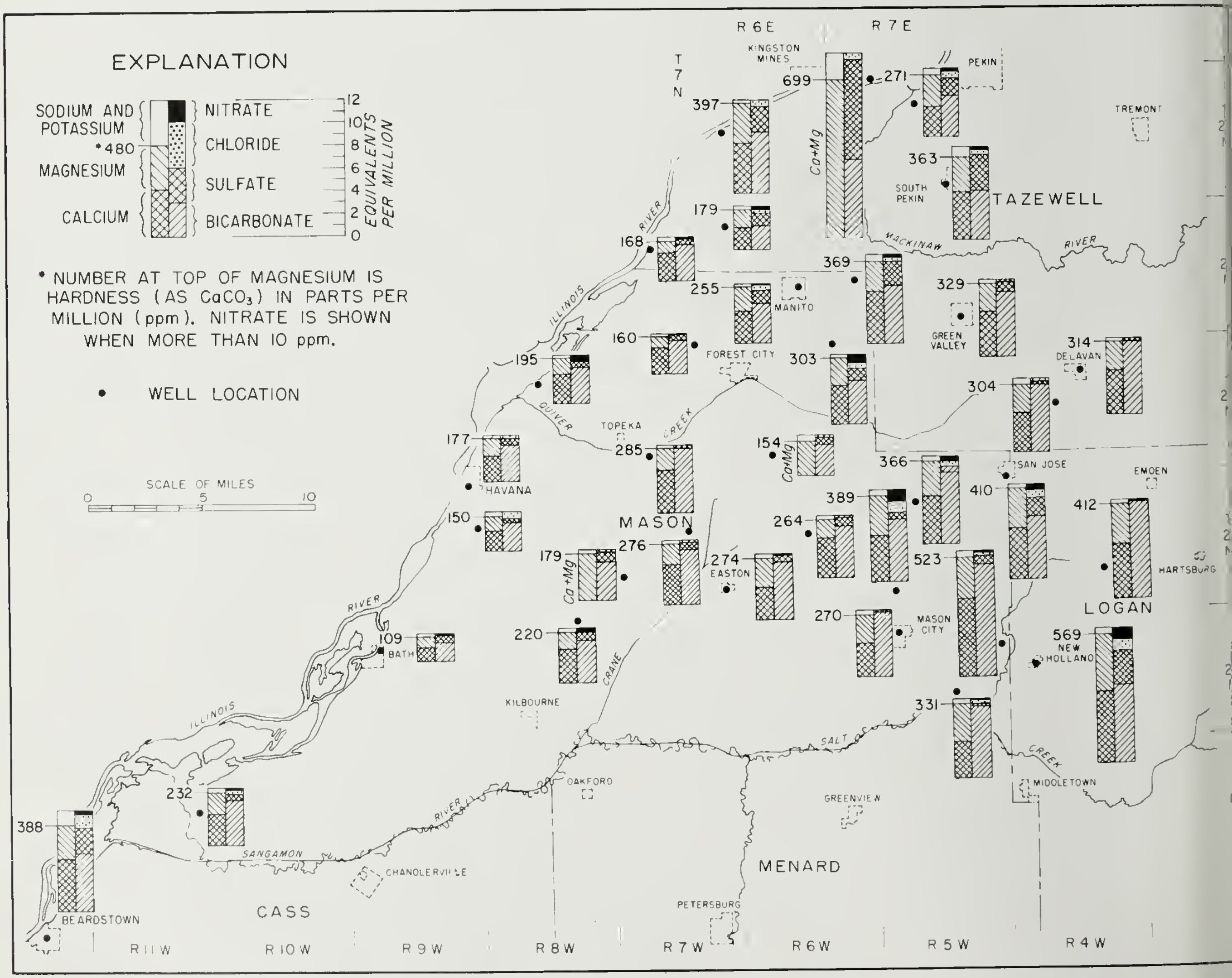


Fig. 41. Chemical analyses of water from selected wells.

ite City areas, exceeds 200,000 gpd/ft. Coefficients ermeability range from 3000 to 1000 gpd/sq ft. arge directly from precipitation averages about 00 gpd/sq mi.

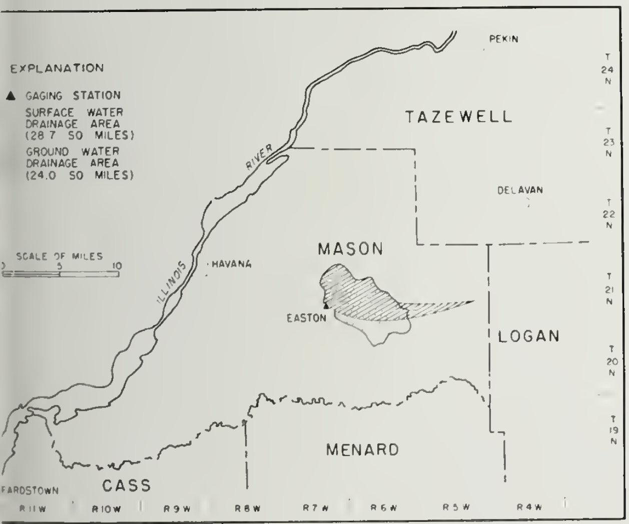
mpage increased from 2.1 mgd in 1900 to 111.0 in and was 93.0 mgd in 1960; as a result of heavy ping, water levels declined about 50 feet in the santo area and more than 10 feet in other pumping ers (Schicht and Jones, 1962, figs. 5 and 34). A metric map for the East St. Louis area (Schicht Jones, 1962, fig. 33) was prepared from water-level surements made in 225 wells in 1961. The general ern of flow of water in that year was slow movement all directions towards cones of depression in pumpcenters and streams in the area. Pumping of wells has considerably reduced ground-water discharge to the Mississippi River but has not at all places reversed the natural slope of the water table toward that stream. Ground-water levels have been lowered below the water surface of the river at places, and appreciable quantities of water were diverted from the river into the aquifer by the process of induced infiltration of surface water.

A comparison between aquifer conditions in the East St. Louis area and in the Havana region seems to indicate that heavy pumping similar to that in the East St. Louis area would result in less water-level decline per unit of pumpage in the Havana region. The aquifer in the Havana region has greater areal extent, thickness, permeability, and average recharge rate than does the aquifer in the East St. Louis area.

SURFACE WATER

reamflow records are available for only one small nage basin contained entirely within the Havana on. This basin is located near Easton in Mason nty, and is drained by a tributary of Crane Creek. ographic divides of this basin do not coincide with ground-water divides; the surface water basin is square miles in area and the ground-water basin 4 square miles in area (fig. 42). Approximately third of the ground-water basin is underlain by consinan outwash deposits; the remainder is underby less permeable Illinoian drift.

treamflow records prepared by the U. S. Geological vey for the Crane Creek tributary basin are availfor the 10-year period, 1950-1959. The average y discharge for years of record is 13.2 cfs. The imum discharge of 425 cfs occurred on February 10, 1959; the minimum of 0.4 cfs occurred on September 20, 1955.



g. 42. Location of the drainage basin of Crane Creek tributary.

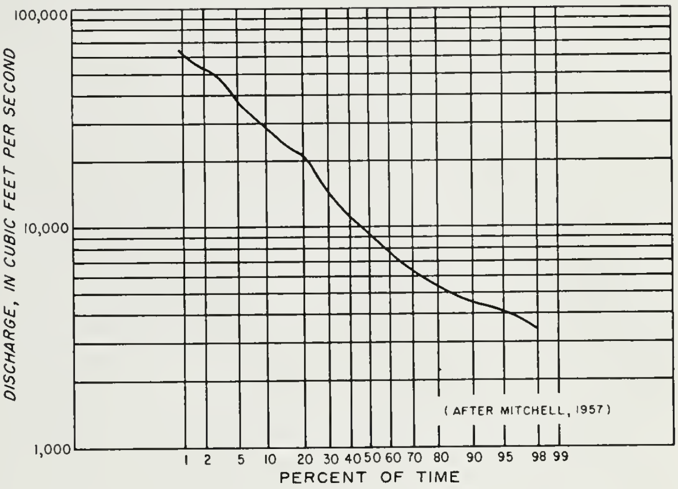


Fig. 43. Flow-duration curve for station at Kingston Mines on the Illinois River.

In general, streamflow is high in winter and spring and low in summer and fall. Streamflow hydrographs have sharp peaks coinciding with heavy rainfall or rapid thaws.

A flow-duration curve for the Illinois River at Kingston Mines is given in figure 43. Daily flows arranged in order of magnitude are plotted against percentage of the time discharges were equaled or exceeded. Thus, the probability of occurrence of specific discharges is indicated. The drainage area of the Illinois River above the gaging station located 2.3 miles downstream from the Mackinaw River in SE¼ SE¼, sec. 26, T. 7 N., R. 6 E., is 15,200 square miles. Since January 17, 1900, flow has included diversion from Lake Michigan through the Chicago Sanitary and Ship Canal. The average daily discharge for the period 1921 through 1945 is 16,800 cfs (10,000 cfs after adjustment for diversion and pumpage). The maximum discharge for the period 1939 through 1950 was 83,100 cfs and occurred on May 23, 1943; the minimum of 2300 cfs occurred on September 27, 1943.

The 32-year average discharge of the Sangamon River for the 5120-square-mile drainage area measured at the gage at Oakford in Menard County is 2989 cfs. The maximum discharge recorded at this gage was 123,000 cfs recorded May 20, 1943; the minimum was 68 cfs (30,600 gpm) recorded December 3, 1940.

The 35-year average discharge of the Mackinaw River for the 1100-square-mile drainage area measured at the gage near Green Valley in Tazewell County is 688 cfs. Maximum discharge through 1956 was 31,000 cfs on July 10, 1951; minimum was 17 cfs (7680 gpm) recorded October 26-27, 1940. Although no discharge measurements of Quiver Creek are available, the average flow in this stream appears to be less than in the Mackinaw River but considerably greater than in Crane Creek.

Ground-Water Runoff

Streamflow consists of surface runoff, R_s, and ground-water runoff, R_g. Surface runoff is precipitation that finds its way into the stream channel without seeping into the soil. Ground-water runoff is precipitation that seeps into the soil or to the water table and then percolates into the stream channel. Surface runoff reaches streams rapidly and is discharged from the basin within a few days. Ground water percolates slowly and reaches streams gradually. Two or three days after precipitation ceases, there is no surface runoff and streamflow is derived entirely from ground-water runoff.

Ground-water runoff depends in part upon the position of the water table because a particular mean ground-water stage is associated with a related hydraulic gradient and a consequent discharge of ground water into a stream. In summer months evapotranspiration reduces ground-water runoff. With the same ground-water levels, much less ground-water runoff occurs in August than in February.

Ground-water runoff generally is at a maximum during spring and early summer months and at a minimum in late summer and fall months. Ground-water runoff often increases in the fall even though the ground-water levels decline because of the rapid decrease in ground-water evapotranspiration during that period. Annual ground-water runoff depends upon antecedent soil moisture and ground-water level conditions as well as the amount and distribution of annual precipitation.

Ground-water runoff to the Crane Creek tributary during 1951, 1956, and 1958 was computed with streamflow data. Precipitation was above normal in 1951, below normal in 1956, and near normal in 1958. In the Crane Creek basin, streamflow consists entirely ground-water runoff three days after rainfall cea During protracted rainless periods, actual streamfl is ground-water runoff. Ground-water runoff un flood hydrographs and during rainless periods was e mated by using streamflow hydrograph separation me ods outlined by Linsley, Kohler, and Paulhus (195

Daily ground-water runoff was plotted beneath strea flow hydrographs, and lines were drawn connect points to describe ground-water runoff hydrographs (44). The shaded areas between streamflow and grou water runoff hydrographs represent surface run Ground-water runoff was 9.3 inches during 1951 a 2.6 inches during 1956. In 1958 when precipitation w near normal, ground-water runoff was 4.7 inch Ground-water runoff amounted to 24, 9, and 13 perc of streamflow in 1951, 1956, and 1958, respectively.

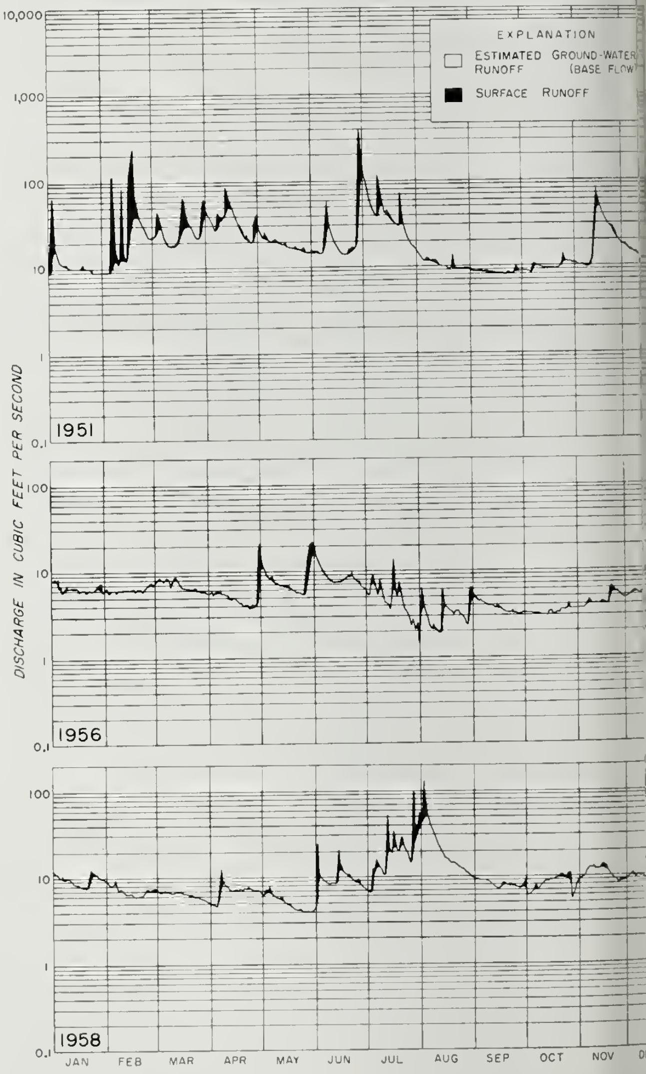


Fig. 44. Streamflow at gaging station, Crane Creek tributary ba for 1951, 1956, and 1958. Location of gaging station is shown i figure 42.

CONCLUSIONS AND RECOMMENDATIONS

e Havana region has four important assets that make it of significant economic importance to central Illinois.

Water resources. A large ground-water reservoir a highly permeable aquifer and favorable condi- for recharge is available. It has not been exten- v developed and offers enough water for substantial ation projects and for industrial use. The Illinois r and other streams, along with numerous floodplain , provide opportunity for water-based recreation.

Other natural resources. Coal, sand and gravel, manageable soils already provide economic benefits ie region, but the land has not been despoiled and possibilities for much more intensive use.

Location. The region is close to several large popu- n centers, yet, with the exception of Pekin, has a l population and much open space.

Transportation. Several railroads, the Illinois erway, and a number of major highways give access ie area.

fore the natural advantages of the Havana region be used successfully, additional studies are needed he water and mineral resources, agricultural man- ient, industrial possibilities and requirements, popu- n projections and urban needs, and alternative land .

the field of ground-water resources, a highly ac- te estimate of the potential yield of aquifers in the ana region must await improved methods of analysis more detailed geologic, hydrologic, meteorologic, and engineering data relating to both ground and surface waters. The following programs are recommended.

1. A collection of additional data on the physical characteristics of the unconsolidated sediments. Such data could be used in evaluating and extrapolating apparent variations in permeability, defining boundaries of aquifers, and determining recharge and other surficial conditions. Geologic data concerned with the nature of the deposits are especially needed for the Illinoian upland east of Easton and for the tributary valleys to the south.

2. Collection of additional data on depth of bedrock, which are needed for mapping the bedrock surface more accurately and determining the thickness of the unconsolidated deposits.

3. Continuation of the collection of data on water levels and pumpage in all pumpage centers so that ground-water development and its effects on water levels can be periodically evaluated.

4. Maintenance of recording gages on two wells in the southern part of the Havana region and on four wells in the northern part to provide continuous records of the character and magnitude of water-level fluctuations.

5. Further aquifer and well-production testing to provide additional information on the hydraulic properties of aquifers.

6. Measurement of water levels in as many wells as possible throughout the Havana region at least once every 10 years to provide data for the preparation of water-table contour maps.

ADDENDUM

Test drilling that took place in the area roughly between Easton and Kilbourne after this report was in press indicates that bedrock topography differs in some significant details from the interpretation given in figure 10.

The following test holes were drilled in 1964:

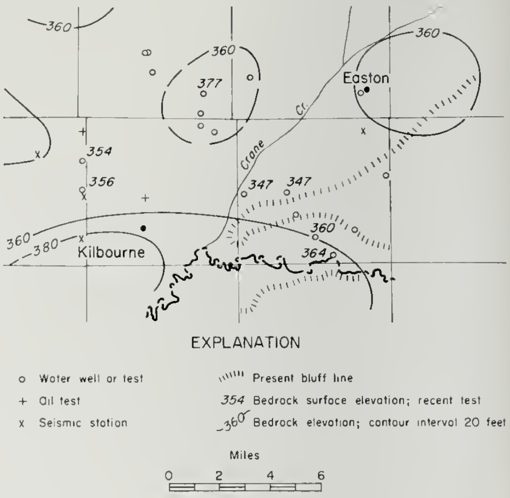
Well number	Owner	Surface elevation (ft)	Total depth (ft)	Thickness of drift (ft)	Bedrock surface elevation (ft)
MSN—					
20N7W-34.8b	Miller	482	119	118	364
20N7W-34.6h	Miller	482	122	122	360
20N7W-21.8h	Branson	507	160	160	347
20N7W-19.5g	Lynn	487	140	140	347
20N9W-24.3h	Leithoff	484	133	128	356
20N9W-12.2a	Kolves	488	134	134	354
21N8W-26.2a	Knuppel	497	124	120	377

The location of the test holes and revision of part of the bedrock topography map warranted by the new data are shown on the map on this page.

The map supersedes figure 10 for the area shown. Other modifications that should be made in figure 10 are as follows:

1. Deletion of 320-foot contour.
2. Deletion of 340-foot contour east of and north of Snicarte.

This does not mean that the bedrock surface in the Havana region is entirely above elevation 340 feet; rather, it means that the deep bedrock channel, if present, does not follow the course or have the width outlined by the 340 and 320 contours in figure 10. It is likely that a channel is present, for a few bedrk surface elevations below 320 feet have been discoved along the Mackinaw and Mahomet Valleys north ad east of the Havana region. Location of the chanl within the area outlined by the 360 contour in fige 10 must await the collection of further data.



Further implications of the recent drilling are tt the total thickness (fig. 14) and saturated thickns (fig. 27) of the unconsolidated deposits between Easn and Kilbourne are less than those shown. Minor adju-ments might be made in the estimates of volume f saturated sediments and water in storage. Howev, the new data do not change the over-all appraisal f ground-water conditions or potential of the region.

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APPENDIX

TABLE A. WATER-LEVEL DATA FOR WELLS IN THE HAVANA REGION

Well number	Owner*	Depth (*ft*)	Diameter (*in*)	Type of well†	Date of measurement	Depth to water below measuring point (*ft*)	Elevation (*ft above m*	
							Water level	Land surface
MSN—								
19N9W-7.2a	C. R. Bell	21	1.25	drv	7-7-60	13.81	462	474
19N9W-11.1h	W. H. Lane	33	1.25	drv	7-7-60	26.65	459	485
19N10W-11.8b	Harold Banks	40	42	dug	7-7-60	35.24	452	485
19N10W-16.8a	S. W. Lucas	29	1.25	drv	7-7-60	13.10	449	465
19N11W-24.4h	Albert Magnus	29	1.25	drv	7-7-60	15.75	443	458
20N5W-8.8f1	Mason City (C)	197	12	D	12-24-60	63.24	517	580
20N7W-3.3a	Myrtle Smith	65	1.25	drv	7-8-60	21.10	492	510
20N7W-22.6d	Howard Ermeling	175	3	D	8-7-60	159.42	483	642
20N8W-1.8c	Fred Kruse	114	18	D	1960	10	489	499
20N8W-2.4e	Ted Kruse	130	18	D	1960	14	490	504
20N8W-4.7e	Lenora Schmidt	17	1.25	drv	7-7-60	8.97	487	494
20N8W-21.4c	Victor Lane	26	1.25	drv	7-7-60	18.09	485	500
20N8W-24.7a	Blaine Close	23	1.25	drv	7-8-60	15.94	474	488
20N8W-32.4a	Glen Hughes	36	1.25	drv	7-7-60	17.32	473	490
20N8W-34.7c	Leonard Stout	38	1.25	drv	9-9-59	27.49	470	490
20N9W-4.8c1	L. F. Connolly	35	1.25	drv	7-7-60	18.34	452	467
20N9W-30.3b	Homer Lascelles	104	18	D	12-59	12	460	472
20N9W-30.4d	Homer Lascelles	26	1.25	drv	7-7-60	14.09	458	468
20N9W-35.1h	C. W. Friend	44	1.25	drv	7-7-60	25.54	476	498
21N5W-3.5h	North Western R.R.	66	5	D	7-26-60	7.97	522	529
21N5W-7.1e	J. F. Watkins	87	6	D	7-27-60	20.06	518	538
21N5W-14.7f	H. B. Smith	67	4	D	7-8-60	50.97	530	581
21N5W-30.2h	Elmer Pierce	99	4	D	7-8-60	78.60	521	600
21N6W-3.3h	Phillip Leinweber	20	1.25	drv	7-26-60	6.21	502	505
21N6W-5.4h	L. J. Pfeiffer	102	6	D	7-26-60	3.33	500	503
21N6W-17.2b	Willis Urish	49	1.25	drv	7-27-60	4.80	505	509
21N6W-23.5e	G. L. Martin	149	6	D	7-27-60	48.35	513	561
21N6W-32.2e	Old County Poor Farm	129	4	D	7-8-60	54.47	505	559
21N6W-35.1b	L. L. Fratzke	89	4	D	7-8-60	67.27	513	580
21N7W-2.1d	E. G. Knuzzel	57	1.25	drv	7-7-60	3.36	495	498
21N7W-4.7g	Frieda Wiemer	27	1.25	drv	7-7-60	19.70	475	494
21N7W-16.1d	H. R. Sinclair	14	1.25	drv	7-27-60	5.09	494	498
21N7W-25.6a	Easton (V)	150	6	D	7-8-60	13.48	498	510
21N7W-27.1h	Joseph Umbach	16	1.25	drv	7-8-60	12.46	491	500
21N7W-30.3f	E. C. Ringhouse	105	18	D	10-59	10	491	501
21N7W-31.3h	John Holstlaw	22.5	1.25	drv	7-8-60	8.73	491	497
21N8W-1.8e	Leslie Henninger	28	1.25	drv	1-6-60	20.90	478	499
21N8W-4.2d	A. N. Larson	21	1.25	drv	7-7-60	19.72	472	489
21N8W-12.7g	Jerry Stephens	48	1.25	drv	7-26-60	21.33	481	501
21N8W-20.1c	H. L. Leiding	32	1.25	drv	7-7-60	8.17	480	487
21N8W-21.4f	Louis Stelter	110	18	D	12-59	10	480	490
21N8W-28.1g	Julius Stelter	122	18	D	1959	13	484	497
21N8W-35.3b	Ted Kruse	122	18	D	12-59	8	489	497
21N8W-36.7b	Jesse Johnson	106	18	D	1-60	6	487	493
21N9W-14.1b	F. C. Speckman	26	1.25	drv	7-7-60	10.99	452	462
21N9W-33.3d	Joseph Sarff	18	1.25	drv	7-7-60	1.40	452	455
22N5W-36.5a	W. S. Palmer	71	5	D	7-26-60	53.90	530	584
22N6W-9.1e	Lewis Warner	46	4	D	8-10-60	13.31	492	505
22N6W-25.5h	Wilford Warner	60	4	D	8-10-60	17.57	497	515
22N6W-28.5h	Nelson Dosier	25	1.25	drv	8-10-60	13.08	497	510
22N6W-33.7b	Earl Pfeiffer	105	18	D	1-60	8	502	510
22N6W-36.1c	Ferd Imig	22	1.25	drv	7-26-60	7.12	510	515
22N7W-3.1h	State of Illinois	31	5	D	7-29-60	22.55	476	499
22N7W-12.1e	Forest City (V)	55	4	D	7-8-60	17.07	484	499
22N7W-17.8a	R. D. LeMasters	42	1.25	drv	7-8-60	38.11	472	506
22N7W-22.4g	Charles Thompson	42	1.25	drv	7-8-60	31.37	471	499
22N7W-23.2d	Theodore Kramer	80	18	D	12-59	13	483	496

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* (C) = city owned; (V) = village owned.
† drv = driven; D = drilled.

TABLE A (Continued)

Vell mber	Owner	Depth *(ft)*	Diameter *(in)*	Type of well†	Date of measurement	Depth to water below measuring point *(ft)*	Elevation *(ft above msl)*	
							Water level	Land surface
–*(continued)*								
7W-24.4e	A. F. Pfeiffer	108	18	D	1-60	9	486	495
7W-25.1g	Olin Kennedy	28	1.25	drv	8-9-60	9.65	490	500
7W-30.4f	J. B. Martin	28	1.25	drv	7-8-60	13.49	463	474
8W-2.2b	S. C. Layman	66	6	D	7-28-60	34.88	440	475
8W-21.1b	E. E. Dierker	26	1.25	drv	7-8-60	10.88	451	463
8W-29.5a	Loveta Hahn	43	1.25	drv	7-8-60	28.81	457	483
6W-26.7a	Lloyd Meeker	24	1.25	drv	8-10-60	20.51	483	501
6W-31.1f	R. L. Mitchell	30	1.25	drv	8-9-60	23.30	495	515
7W-24.2h	Evert Palmer	59	5	D	7-29-60	50.47	475	523
7W-29.4a	F. I. Mitchell	46	1.25	drv	7-28-60	41.95	455	497
–								
E-29.2d1	Archer-Daniels-Midland	73	16	D	10-24-60	4.97	440	443
–								
3W-17.6h	Timothy Swain	270	4	D	8-25-60	164.97	545	710
4W-10.4g	H. R. Pieper	142	4	D	8-26-60	95.91	529	625
4W-16.8b1	Hiram Walker & Co.	212	6	D	4-20-60	24.5	526	551
4W-23.8b	May D. Cole	96	4	D	8-25-60	50.60	534	585
4W-29.1a	N. C. Yontz	113	6	D	8-25-60	44.23	536	580
5W-1.1d	Don Burns	104	4	D	8-25-60	22.60	517	540
5W-7.8f	Bruce Crosby	24	1.25	drv	8-10-60	16.83	498	515
5W-10.1d	Thomas Frazel	99	4	D	8-25-60	8.98	513	522
5W-13.1e	R. V. Grimmer	23	1.25	drv	8-25-60	7.95	523	531
5W-20.1h	Paschal Allan	28	1.25	drv	8-12-60	13.74	510	524
4W-29.6d	Ralph Allen	85	2.50	D	8-24-60	52.43	513	565
5W-2.5e	C. H. Calhico	60	4	D	8-22-60	15.01	488	503
5W-5.4f	Peter Fuelberth	47	60	dug	8-23-60	40.90	470	511
5W-7.7b	Johnanna Proehl	22	1.25	drv	8-23-60	9.93	460	468
5W-17.1a	Kenneth Everly	14	1.25	drv	8-24-60	8.84	474	480
5W-27.1b	Van Nattan	106	4	D	8-25-60	35.96	501	537
5W-29.7a	Cary Crawford	102	4	D	8-23-60	51.32	490	541
6W-6.4a	Henry Fornoff	64	4	D	8-23-60	56.69	465	522
6W-11.8h	Irma Terhune	20	1.25	drv	8-23-60	12.12	460	471
6W-16.5a	Glen Talbott	68	4	D	8-11-60	49.19	473	522
7W-3.4e	Frank Schachtrup	24	10	bored	8-22-60	5.90	430	436
5W-3.7b	Corn Products Co.	98	26	D	5-23-62	37.2	424.0	461.2
					8-1-62	42.2	418.0	
5W-3.7c1	Corn Products Co.	98	26	D	5-23-62	40.8	421.8	462.6
					8-1-62	45.9	416.7	
5W-3.7c2	Corn Products Co.	99	26	D	5-23-62	40.1	419.1	459.2
					8-1-62	28.0	431.2	
5W-3.8a	Corn Products Co.	83	26	D	7-15-60	25	435	460.0
					5-23-62	25.9	434.1	
					8-1-62	29.8	430.2	
5W-3.8b	Corn Products Co.	91	26	D	5-23-62	34.3	420.9	455.2
					8-1-62	44.0	411.2	
5W-4.1b	Corn Products Co.	90	26	D	5-23-62	25.7	433.0	458.7
					8-1-62	29.7	429.0	
5W-4.1c	Corn Products Co.	.	26	D	5-23-62	26.7	432.0	458.7
					8-1-62	31.7	427.0	
5W-4.2b	American Distilling	104	26	D	5-23-62	26.7	433	459.7
					8-1-62	33.7	426	
5W-4.3a	American Distilling	85	26	D	5-23-62	32.2	432	464.2
					8-1-62	37.2	427	
5W-4.3b1	American Distilling	85	24	D	5-23-62	26.8	432	458.8
					8-1-62	32.4	426	
5W-4.3b2	American Distilling	85	24	D	7-10-60	27	433	459.0
					5-23-62	26.0	433	
					8-1-62	30.7	428	

TABLE A (Concluded)

Well number	Owner	Depth (ft)	Diameter (in)	Type of well†	Date of measurement	Depth to water below measuring point (ft)	Elevation (ft above Water level	 Land surfa
TAZ—(*continued*)								
24N5W-4.4a	American Distilling	80	20	D	5-23-62	28.3	435	46
					8-1-62	......	......	
24N5W-9.1g1	Standard Brands Inc.	76	25	D	7-10-60	27.5	433	46
					5-23-62	28.7	431.3	
					8-1-62	32.0	428.0	
24N5W-9.1g2	Standard Brands Inc.	88	30	D	5-23-62	47.0	429.4	47
					8-1-62	50.4	426.0	
24N5W-9.1g3	Standard Brands Inc.	99	26	D	5-23-62	54.4	428.0	48
					8-1-62	56.4	426.0	
24N5W-9.1g4	Standard Brands Inc.	87	8	D	5-23-62	45.0	433.3	47
					8-1-62	48.6	429.7	
24N5W-9.1h1	Quaker Oats Co.	51	17	D	5-21-62	11.4	432.8	44
					8-1-62	14.8	429.4	
24N5W-9.1h2	Quaker Oats Co.	78	25	D	5-21-62	28.9	433.3	46
					8-1-62	31.2	430.9	
24N5W-9.1h3	Standard Brands Inc.	95	26	D	5-23-62	45.8	427.0	47
					8-1-62	48.8	424.0	
24N5W-9.1h4	Standard Brands Inc.	75	8	D	5-23-62	25.6	433.4	45
					8-1-62	28.5	430.5	
24N5W-9.1h6	Standard Brands Inc.	73	30	D	5-23-62	37.1	427.0	46
					8-1-62	38.5	425.6	
24N5W-9.2f	Standard Brands Inc.	78	30	D	5-23-62	26.5	438.6	46
					8-1-62	43.5	421.6	
24N5W-9.2g1	Standard Brands Inc.	76	25	D	5-23-62	41.5	425.6	467
					8-1-62	47.0	420.1	
24N5W-9.2g2	Standard Brands Inc.	70	25	D	5-23-62	22.5	439.7	46
					8-1-62	27.2	435.0	
24N5W-9.2g4	Standard Brands Inc.	81	30	D	5-23-62	27.3	435.1	46
					8-1-62	31.2	431.2	
24N5W-9.6a	Commonwealth Edison	62	25	D	5-23-62	29.5	440.0	46
					8-1-62	31.5	438.0	
24N5W-9.7a	Commonwealth Edison	72	25	D	5-23-62	30.6	444.4	47
					8-1-62	31.6	443.4	
24N5W-9.7c	Commonwealth Edison	60	24	D	5-23-62	22.5	439.5	462
					8-1-62	28.0	434.0	
24N5W-9.8a	Commonwealth Edison	63	25	D	5-23-62	26.8	439.7	466
					8-1-62	29.3	437.2	
24N5W-9.8b1	Commonwealth Edison	59	25	D	5-23-62	23.7	436.8	460
					8-1-62	22.7	437.8	
24N5W-9.8b2	Commonwealth Edison	67	25	D	5-23-62	28.5	439.5	468
					8-1-62	40.0	428.0	
24N5W-9.8b3	Commonwealth Edison	64	25	D	5-23-62	29.2	439.3	468
					8-1-62	32.7	435.8	
24N5W-9.8c1	Commonwealth Edison	56	25	D	5-23-62	19.7	438.3	458
					8-1-62	24.7	433.3	
24N5W-9.8c2	Commonwealth Edison	60	25	D	5-21-62	25.2	436.8	462
					8-1-62	27.7	434.3	
24N5W-9.8c3	Commonwealth Edison	61	25	D	5-21-62	27.0	435.0	462
					8-1-62	31.0	431.0	
24N5W-9.8c4	Commonwealth Edison	65	24	D	7-10-60	22.5	437	460
					5-21-62	20.4	439.6	
					8-1-62	24.5	435.5	
24N5W-10.8h1	Quaker Oats Co.	79	17	D	5-21-62	30.3	434.3	464
					8-1-62	33.2	431.4	
24N5W-10.8h2	Quaker Oats Co.	87	18	D	5-21-62	32.1	433.0	465
					8-1-62	36.0	429.1	
24N5W-10.8h3	Quaker Oats Co.	90	18	D	5-21-62	37.4	432.0	469
					8-1-62	41.4	428.0	
24N5W-20.2h	Pete Bailey	90	4	D	8-22-60	60.25	455	514
24N5W-29.5a	Eidman School	58	4	D	8-23-60	44.28	466	510
24N5W-30.6c	Kenneth Lutz	23	1.25	drv	8-24-60	12.66	457	468
24N6W-1.1a	Archer-Daniels-Midland	68	6–1.25	drv	10-24-60	2.18	433	434
24N6W-9.6e	L. H. Vawter	12	10	bored	10-24-60	5.71	429	435
24N6W-21.7f	B. H. Wise	19	1.25	drv	10-24-60	14.04	441	455
24N6W-23.3h	W. E. Lowry	63	4	D	8-24-60	44.04	440	484
24N6W-33.1h	J. J. Waddell	59	4	D	8-23-60	47.52	453	501
24N7W-25.4h	Marilyn Pallor	36	4	D	8-22-60	7.03	429	436
24N7W-27.6e	Anna Helm	11	8	bored	8-22-60	5.08	430	435

TABLE B. PRODUCTION RECORDS OF LARGE-CAPACITY WELLS IN THE HAVANA REGION

ell ber	Owner*	Year drilled	Well		Screen			Non-pumping water level (ft)	Well-production test			Observed specific capacity (gpm/ft)	Remarks
			Depth (ft)	Diameter (in)	Length (ft)	Diameter (in)	Slot size (in)		Length of test (min)	Discharge rate (gpm)	Drawdown (ft)		
V-14.8h	Beardstown (C)	1959	89	36–16	20	16	.080	19	10	400	6.0	67	Well 2; gravel pack
									10	620	9.3	67	
									10	800	12.6	63	
V-15.2f	Beardstown (C)	1956	86	36–16	25	16	.110	16	60	600	3.7	161	Well 1; gravel pack
									60	800	5.2	154	
									60	1000	6.7	159	
-31.7b2	Chandlerville (V)	1936	32	36–16	26	16	4 x 3/16	11.5	1440	154	7.9	20	Concrete casing and screen; gravel pack
-18.1b	New Holland (V)	1931	74	6	10	6	.014–.024	34	.	40	..	....	North well; natural pack
V-24.8b	Albert Magnus	1956	65	6	10	6	.050	4	180	550	21	26	Natural pack
-8.8e	Chicago & Alton R.R.	1926	216	10	20	10	.025	53	270	55	5	11	Natural pack
-8.8f1	Mason City (C)	1916	197	12	12	12	.030	63	5	100±	8.5	10	South well; natural pack
-8.8f2	Mason City (C)	1928	222	12	12	12	.030	64	5	200±	18.2	10	North well; natural pack
-2.3h	Ted Kruse	1962	60	8	20	8	2 x 3/8	4.5	180	60	1.7	35	No. 16-gage iron casing and slotted pipe screen; natural pack
-2.4e	Ted Kruse	1959	130	36–16	62	16	4 x 3/16	14	..	....	10	....	Well 1; concrete casing and screen; gravel pack
-30.3b	Homer Lascelles	1959	104	36–16	54	16	4 x 3/16	12	..	750	7.3	102	Concrete casing and screen; gravel pack
-4.3g	L. C. Pfeiffer	1961	102	36–16	20	16	4 x 3/16	14	270	700	12	58	Concrete casing and screen; gravel pack
-5.7f	Ray Carpenter	1962	128	36–16	40	16	4 x 3/16	16.0	270	1480	12.3	120	Concrete casing and screen; gravel pack
-15.3f	Burnell Steinhauer	1959	119	36–16	50	16	4 x 3/16	7	....	1400	....	....	Concrete casing and screen; gravel pack
-15.7f	Burnell Steinbauer	1962	112	36–16	52	16	4 x 3/16	6.7	360	650	3.7	175	Concrete casing and screen; gravel pack
-25.6a	Easton (V)	1955	150	6	10	6	.025	13.5	....	....	....	....	Fire protection well; natural pack
-25.7a	Easton (V)	1960	135	8	15	8	.025	15.5	150	110	3.5	32	Well 1; natural pack
-30.3f	E. C. Ringhouse	1959	105	36–16	40	16	4 x 3/16	10	120	1310	20	66	Concrete casing and screen; gravel pack
-1.8c	Fred Kruse	1959	114	36–16	50	16	4 x 3/16	10	....	...	....	....	Formerly Ted Kruse well 2; concrete casing and screen; gravel pack
-6.5d	Chicago & Ill. Midland R.R.	1949	92	6	4	6	.030	15	...	50	15	3.4	Natural pack
-16.1b	Mervin Roat	1962	108	36–16	24	16	4 x 3/8	7.0	225	850	12.8	67	Concrete casing and screen; gravel pack
-21.4f	Louis Stelter	1959	110	36–16	60	16	4 x 3/16	10	..	....	....	...	Well "B"; concrete casing and screen; gravel pack
-28.1g	Julius Stelter	1959	122	36–16	56	16	4 x 3/16	13	180	1000	4.3	230	Concrete casing and screen; gravel pack
-35.3b	Ted Kruse	1959	122	36–16	60	16	4 x 3/16	8	...	....	..	.	Well 3; concrete casing and screen; gravel pack
-36.7b	Jesse Johnson	1960	106	36–16	40	16	4 x 3/16	6	180	1150	10	115	Concrete casing and screen; gravel pack
-1.1f1	Havana (C)	1942	85	12	15	12	.040	22	...	950	7	135	Well 2; natural pack
-1.1f2	Havana (C)	1960	78	12	20	12	.030	24	480	1000	26	38	Well 4; natural pack
-1.2f	Havana (C)	1952	125	12	35	12	.035	55	300	635	21.5	30	Well 3; natural pack
V-11.2c1	Illinois Power Co.	1946	84	30–18	15	18	.080	29	...	....	....	....	Well 1; gravel pack
V-11.2c2	Illinois Power Co.	1946	83	30–18	15	18	.080	17.6	480	410	10	41	Well 2; gravel pack
V-11.2c3	Illinois Power Co.	1946	79	30–18	15	18	.080	26	480	430	....	....	Well 3; gravel pack
V-11.2c4	Illinois Power Co.	1948	83	30–18	15	18	.080	30	480	500	10	50	Well 4; gravel pack
V-33.7b	Earl Pfeiffer	1960	105	36–16	28	16	4 x 3/16	8	120	750	6.3	118	Well on Louis Pfeiffer farm; concrete casing and screen; gravel pack
V-23.2d	Theo. & Mabel Kramer	1959	80	36–16	44	16	4 x 3/16	13	180	1735	12	144	Concrete casing and screen; gravel pack
V-24.4e	Alvin Pfeiffer	1960	108	36–16	40	16	4 x 3/16	9	180	1150	10	115	Concrete casing and screen; gravel pack
V-24.5g	Alvin Pfeiffer	1962	113	36–16	40	16	4 x 3/16	11.2	180	600	3.8	158	Concrete casing and screen; gravel pack
V-24.7b	Alvin Busch	1962	105	36–16	40	16	4 x 3/16	7.0	150	600	5.2	115	Concrete casing and screen; gravel pack
V-25.7h	Mabel Kramer	1962	95	36–16	40	16	4 x 3/16	5.1	270	1200	12.1	99	Concrete casing and screen; gravel pack
V-27.2c	Glenn Strube	1961	125	36–16	40	16	4 x 3/16	14.6	180	1200	12.2	99	Concrete casing and screen; gravel pack
V-33.8h	Mason State Tree Nursery	1936	136	6	10	6	.060	28	60	210	23	9.1	Natural pack
									60	235	28	8.4	
V-34.6c	Glenn Strube	1961	127	36–16	40	16	4 x 3/16	13	240	1225	13	95	Concrete casing and screen; gravel pack

---

city owned; (V) = village owned.

TABLE B (Continued)

Well number	Owner*	Year drilled	Well		Screen			Non-pumping water level *(ft)*	Well-production test			Observed specific capacity *(gpm/ft)*	Remarks
			Depth *(ft)*	Diameter *(in)*	Length *(ft)*	Diameter *(in)*	Slot size *(in)*		Length of test *(min)*	Discharge rate *(gpm)*	Drawdown *(ft)*		
MSN—*(continued)*													
22N8W-9.2a	Chautauqua Wildfowl Refuge	1938	70	6	7	6	.030	6	90	50	7	7	Natural pack
23N6W-21.3d	Manito (V)	1937	81	10	20	10	.025	33	60 60	120 255	2 7	60 36	Well 1; natural p
PEO—													
7N7E-28.6e1	Toledo, Peoria & Western R.R.	1959	67	8	15	6	.040	5.25	15 15 15 1132	280 327 378 430	1.70 2.06 2.53 3.31	165 159 150 130	Test well 12-59; pack
7N7E-28.6e2	Toledo, Peoria & Western R.R.	1959	64	1.25	3	.25	.010	2.86	....	....	....	....	Observation well natural pack
7N7E-28.7e	Toledo, Peoria & Western R.R.	1959	64	1.25	3	1.25	.010	5.66	....	....	....	....	Observation well natural pack
7N7E-28.8d	Toledo, Peoria & Western R.R.	1959	64	1.25	3	1.25	.010	4.30	....	....	....	....	Observation well natural pack
7N7E-29.1d	Archer-Daniels-Midland	1960	75	6	6	5	.....	11.22	....	....	....	....	Observation well slotted pipe scre natural pack
7N7E-29.2d1	Archer-Daniels-Midland	1960	73	16	20	16	.100	3.5	60 60 60 3990	500 750 1000 985	9 14 20 20.7	55.5 53.5 50 47.5	Test well 16-1-60 natural pack
7N7E-29.2d2	Archer-Daniels-Midland	1960	73	6	6	5	......	4.86	....	....	....	....	Observation well slotted pipe scre natural pack
7N7E-29.2d3	Archer-Daniels-Midland	1960	72	6	6	5	.....	3.96	....	....	....	....	Observation well slotted pipe scre natural pack
TAZ—													
22N4W-16.8a	Hiram Walker & Sons	1960	213	42–18	80	18	.035	43	30 30 540	1350 1720 2250	13.2 17 23	102 101 98	Well 2; gravel pa
22N4W-16.8b1	Hiram Walker & Sons	1960	212	6	15	6	.014	34	15 15 350	112 151 200	6.09 8.28 11.20	18.4 18.2 18	Well 3; natural p
22N4W-16.8b2	Hiram Walker & Sons	1960	209	46–16	80	16	.030	37	60 60 360	1525 2250 2250	16 25 25	95 90 90	Well 1; gravel pa
23N5W-26.8a1	Green Valley (V)	1948	115	8	8	8	.020	33	60 60	128 149	11.3 13.3	11.3 11.2	Well 1; natural p
24N5W-3.7b	Corn Products Co.	1937	98	38–26	20	26	.080	22	480	1188	14	85	Well 2; gravel pac
24N5W-3.7c1	Corn Products Co.	1939	98	38–26	20	26	.080	31	480	1224	18	68	Well 3; gravel pac
24N5W-3.7c2	Corn Products Co.	1947	99	38–26	20	26	.080	26	480	915	15	61	Well 5; gravel pac
24N5W-3.8a	Corn Products Co.	1937	83	38–26	20	26	.080	19.5	480	1300	23	56	Well 1; gravel pac
24N5W-3.8b	Corn Products Co.	1942	91	38–26	13	26	.080	26	480	960	14	68	Well 4; gravel pac
24N5W-4.1b	Corn Products Co.	1951	90	38–26	20	26	.055	26	480	919	14	65	Well 6; gravel pac
24N5W-4.1c	Corn Products Co.	1955	....	38–26	20	26	....	26	600	900	8	112	Well 7; gravel pac
24N5W-4.2b	American Distilling	1943	104	38–26	18	26	.080	26	480	1500	14	107	Well 1; gravel pac
24N5W-4.3a	American Distilling	1957	85	48–26	20	26	.080	24	480	1400	16	88	Well 5; gravel pac
24N5W-4.3b1	American Distilling	1933	85	24	20	24	......	21	....	2000	....	....	Well 2; natural pa
24N5W-4.3b2	American Distilling	1933	85	24	20	24	......	21	....	1000	....	......	Well 3; natural pa
24N5W-4.4a	American Distilling	1936	80	20	30	20	......	....	360	3000	20.7	145	Well 4; natural pa
24N5W-9.1g1	Standard Brands, Inc.	1928	74	36–25	39	25	......	21	....	....	....	....	Well 3; concrete c and screen; grav
24N5W-9.1g2	Standard Brands, Inc.	1950	88	48–30	20	30	.105	44	60 60 465	1016 1460 1016	8 14 9	127 104 113	Well 8; gravel pac
24N5W-9.1g3	Standard Brands, Inc.	1940	99	26	20	26	....	....	....	850	21	40	Well 7; natural pa
24N5W-9.1g5	Standard Brands, Inc.	1926	76	36–25	38	25	....	20	....	450	3	150	Well 1; concrete c and screen; grav
24N5W-9.2g1	Standard Brands, Inc.	1926	76	36–25	38	25	..	20	.	450	3	150	Well 2; concrete c and screen; grav
24N5W-9.2g2	Standard Brands, Inc.	1931	70	36–25	43	25	....	25		1890	18.2	104	Well 4; concrete c and screen; grav
24N5W-9.2g3	Standard Brands, Inc.	1935	79	26	20	26	.....	27	...	2475	....	....	Well 5; gravel pac
24N5W-9.2g4	Standard Brands, Inc.	1952	81	48–30	20	30	.105	38	540	1064	20	53	Well 9; gravel pac
24N5W-9.1h1	Quaker Oats Co.	1924	51	38–17	25	25	......	17	....	600	6	100	Well 1; concrete s and casing; grav
24N5W-9.1h2	Quaker Oats Co.	1929	78	42–25	34	25	......	18	..	600	5.5	109	Well 2; concrete c and screen; grav
24N5W-9.1h3	Standard Brands, Inc.	1940	95	38–26	15	26	.125	46	..	2426	37	66	Well 6; gravel pac
24N5W-9.1h6	Standard Brands, Inc.	1954	73	48–30	20	30	.105	46	540	1000	22	45	Well 10; gravel pa
24N5W-9.2f	Standard Brands, Inc.	1956	78	48–30	20	30	.105	43	450	1036	12.7	80	Well 11; gravel pa
24N5W-9.6a	Commonwealth Edison	1938	62	38–25	26	25	......	26	300	1000	20	50	Well 8A; concrete and screen; grav
24N5W-9.7a	Commonwealth Edison	1948	72	38–25	24	25	......	30	330	1025	16.5	62	Well 11; concrete and screen; grav
24N5W-9.7c	Commonwealth Edison	1927	60	24	40	24	......	24	..	1609	12.7	125	Well 1; slotted pip screen; natural p

TABLE B (Concluded)

ll ber	Owner*	Year drilled	Well		Screen			Non-pumping water level *(ft)*	Well-production test			Observed specific capacity *(gpm/ft)*	Remarks
			Depth *(ft)*	Diameter *(in)*	Length *(ft)*	Diameter *(in)*	Slot size *(in)*		Length of test *(min)*	Discharge rate *(gpm)*	Drawdown *(ft)*		
ntinued)													
9.7d	Commonwealth Edison	1927	64	24	40	24	......	24	....	1360	22.2	58	Well 2; slotted pipe screen; natural pack
9.8a	Commonwealth Edison	1940	63	38–25	24	25	......	31	180	1050	15	70	Well 9; concrete casing and screen; gravel pack
9.8b1	Commonwealth Edison	1944	59	38–25	30	25	......	28	30 30 240	1925 2000 1875	13.2 14 15.5	145 143 121	Well 6A; concrete casing and screen; gravel pack
9.8b2	Commonwealth Edison	1941	67	38–25	22	25	......	40	240	1300	20	65	Well 7A; concrete casing and screen; gravel pack
-9.8b3	Commonwealth Edison	1940	64	38–25	23	25	......	27	180	900	17	53	Well 10; concrete casing and screen; gravel pack
-9.8b4	Commonwealth Edison	1930	57	24	40	24		21	360	1700	....	....	Well 6; slotted pipe screen; natural pack
-9.8b5	Commonwealth Edison	1930	67	38–25	38	25	......	34	30 30	550 1000	3.5 6.7	156 148	Well 7; concrete casing and screen; gravel pack
-9.8b6	Commonwealth Edison	1930	67	2	38	2	......	34	....	....	....	....	Driven
-9.8c1	Commonwealth Edison	1943	56	38–25	25	25	......	32	270	1720	....	....	Well 3A; concrete casing and screen; gravel pack
-9.8c2	Commonwealth Edison	1943	60	38–25	25	25	......	32	180	1990	....	....	Well 4A; concrete casing and screen; gravel pack
-9.8c3	Commonwealth Edison	1942	61	38–25	21	25	......	32	120	1730	17	102	Well 5A; concrete casing and screen; gravel pack
-9.8c4	Commonwealth Edison	1928	65	24	40	24	......	27	....	1620	19.5	83	Well 3; slotted pipe screen; natural pack
-9.8c5	Commonwealth Edison	1930	58	24	40	24	......	21	480	1170	21	54	Well 4; slotted pipe screen; natural pack
-9.8c6	Commonwealth Edison	1930	58	24	40	24	......	25	330	1600	12.7	123	Well 5; slotted pipe screen; natural pack
-10.8h1	Quaker Oats Co.	1941	79	38–17	25	17	......	32	....	850	11	77	Well 3; gravel pack
-10.8h2	Quaker Oats Co.	1955	87	38–18	20	18	.080	40	....	869	10	87	Well 4; gravel pack
-10.8h3	Quaker Oats Co.	1958	90	38–18	20	18	.080	41	....	1056	13	81	Well 5; gravel pack
-1.1a	Archer-Daniels-Midland	1960	68	6– 1.25	3	1.25	.010	2.18	....	....	....	....	Observation well 6-6-60; located across Illinois River from well 16-1-60; driven

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ILLINOIS STATE WATER SURVEY
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COAL AND WATER RESOURCES FOR COAL CONVERSION IN ILLINOIS

William H. Smith and John B. Stall

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION

1975

COAL AND WATER RESOURCES FOR COAL CONVERSION IN ILLINOIS

WILLIAM H. SMITH and JOHN B. STALL

TATE WATER SURVEY
STATE GEOLOGICAL SURVEY

COOPERATIVE RESOURCES REPORT 4

RBANA, ILLINOIS
1975

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FOREWORD

The Illinois State Geological Survey and the Illinois State Water Survey have long collected and interpreted information on coal and water resources of Illinois. Many publications concerning these resources have provided authoritative data for a wide range of government agencies, industries, and private citizens.

In mid-1973, aware of the need for basic information about coal and water resources for use in siting coal conversion plants, the two Surveys embarked on a joint project to fill that need. In this publication all available information has been updated and put into a form convenient for assessing resources at sites that could be selected for coal conversion plants.

We believe that the data base on which this study was founded permits a comprehensive interpretation of coal and water resources in Illinois. Results indicate that Illinois has large resources of both coal and water. In addition, many other conditions relevant to the siting of coal conversion plants are so favorable that Illinois could provide excellent sites for a number of such plants.

William C. Ackermann, Chief
Illinois State Water Survey

Jack A. Simon, Chief
Illinois State Geological Survey

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Coal and Water Resources for Coal Conversion in Illinois

William H. Smith and John B. Stall

ABSTRACT

Illinois has enormous reserves of coal and water. Nearly 100 billion tons of coal have been mapped in the two thickest and most extensive seams in the state, and numerous potential areas having sufficient water to supply one or more coal conversion plants have been evaluated and mapped. These resources of coal and water are sufficient to supply raw materials for many coal conversion plants that could provide synthetic fuels to help meet the rapidly expanding need for new energy sources in the Midwest and the eastern United States.

The report provides an up-to-date assessment of the state's most promising resources of coal and water. Three large maps included in the report show the geographic distribution of the coal and water. Supplementary maps and tables provide the fundamental information on coal and water resources that will be needed by the government agencies and private industries ultimately responsible for decisions regarding the siting of coal conversion facilities.

Remaining in-place reserves 42 or more inches thick total 59 billion tons for the Herrin (No. 6) Coal and 38 billion tons for the Harrisburg–Springfield (No. 5) Coal. In addition, reserves of the Harrisburg–Springfield and Herrin Coals that are less than 42 inches thick plus reserves in other Illinois coal seams total about 64 billion tons. The total reserves, therefore, constitute the largest reserves of bituminous coal in any state in the nation. The importance of these reserves is increased by the fact that 56 percent of the Herrin mapped for this report is 6 feet or more thick and 47 percent of the mapped Harrisburg–Springfield is 5 feet or more thick.

The report also locates sources of water capable of producing the 6 to 72 million gallons per day estimated to be required by coal conversion plants. The abundant reserves of coal and water documented in the report can support a synthetic fuels industry in Illinois large enough to contribute significantly to the energy needs not only of Illinois but of the surrounding regions.

INTRODUCTION

The state of Illinois, whose agricultural and mineral ealth and strategic location have made it a center of comierce and industry, contains enormous mapped resources . f bituminous coal, only 5.2 percent of which has been epleted. The coal occurs in beds, or layers, varying from ss than a foot to as much as 10 feet thick. A number of ie beds are of minable thickness over many thousands of quare miles. The two thickest and most widespread of iese, the Herrin (No. 6) Coal and the Harrisburg–Springeld (No. 5) Coal, have supplied most of the coal needs of ie state for the past 100 years, during which time 4.5 bilon tons has been produced. In 1918, the year of highest oal production in Illinois history, 966 coal mines in Illinois roduced a total of 88 million tons of coal. Illinois now anks fourth among coal-producing states; in 1974 it had 55 iines that produced 58 million tons of coal, most of which as used for electric power generation. Because oil and gas re cleaner and more convenient to use and because of their ow price after World War II, a large and efficient network f oil and gas pipelines and storage facilities was established. onsequently, coal lost many of its markets.

Today, as the nation is well aware, reserves of oil and gas are declining and in the future cannot be relied upon to meet the ever-increasing energy demands. The undesirability of depending on foreign sources for much of our oil has aroused great interest in other domestic fuels. One alternative source of energy is the conversion of coal to gas or liquid fuels that are environmentally more acceptable than coal itself. Synthetic fuels from coal will be needed in increasingly large quantities to meet future energy needs.

Illinois offers outstanding advantages for the development of facilities for coal conversion by both liquefaction and gasification. Some of these have been presented in a recent report by Hogland and Asbury (1974),* prepared for the Illinois Institute for Environmental Quality. Among the factors favorable for locating coal conversion plants in Illinois are the huge reserves of relatively thick bituminous coal, mining conditions that are generally favorable for large-scale mining and high productivity, abundant and diverse sources of water, the location of the state in a large industrial and consuming area that has a well developed road and railroad network, easy access to many interstate oil and gas pipelines, and the availability of many existing and potential sites for underground storage of gas.

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* Reference cited in Bibliography at the end of Part 1, under the heading "Coal Conversion."

Purpose and Scope

The distribution, thickness, and quality of coal in Illinois has been studied for many decades by the Illinois State Geological Survey, and the Illinois State Water Survey for a corresponding period has investigated the availability and quality of water resources in the state. This report re-evaluates and summarizes the information available on the major coal resources (Part 1) and water resources (Part 2) in light of their availability for prospective coal conversion facilities in Illinois. Inasmuch as the Herrin (No. 6) and the Harrisburg-Springfield (No. 5) Coal Members constitute approximately 85 percent of the previously mapped coal reserves 42 or more inches thick, they alone were evaluated in this study.

The potential sources of water in the large quantities that will be needed by a single coal conversion plant were located by the Water Survey. They include (1) ground water from shallow and deep aquifers, (2) surface water from rivers, (3) existing and potential man-made reservoirs, and (4) treated wastewaters.

Water needs for coal conversion plants, based on estimates reported in the literature, range from a very low 6 million gallons per day (mgd) under extreme conservation measures, through a more normal low requirement of 14 mgd, to a high of 72 mgd. This range has been used as a basis for determining the availability of the water resources of the state for coal conversion.

No attempt is made in this study to evaluate various conversion processes or to assess many other factors that must be considered in locating coal conversion plants, many of which may be important determinants in site selection. Because availability of sufficient coal and water is so vital, however, we have attempted to assemble all data for the principal coal deposits and potential water sources and to present these data in the form most useful for site evaluation. The basic information on coal and water in the files of the Geological Survey and the Water Survey are accessible for further studies. Systems analysis can be used to interrelate these data with other types of information that can be used to determine the best sites for coal conversion facilities.

This report is the fourth in a series of cooperative reports by the two Surveys. The three previous reports concerned ground-water resources of the Chicago Region (Suter et al., 1959), Du Page County (Zeizel et al., 1962), and the Havana Region (Walker, Bergstrom, and Walton, 1965).*

Conversion of Coal

Gas has been commercially manufactured from coal sin the early 19th century. Nearly every major city in th eastern United States once had its own gas plant where g was manufactured from coal for domestic uses. After Worl War II, when natural gas pipelines were extended to mo communities, the gas from coal plants was no longer neede Liquid fuels also have been extracted from coal for man years, and gasoline made from coal was widely used Germany in the later years of World War II. In Sout Africa gasoline has been produced from coal for sever years.

Much research is being devoted to development of larg scale coal gasification and coal liquefaction processes. Olde technologies are being modified for greater productio while numerous entirely new concepts of coal conversio are being developed, none of them yet operative on a com mercial scale. Different processes for gasification of co produce different types of gas: (1) gas with a low heatin value (100 to 200 British thermal units per standard cubi foot [Btu/scf]); (2) gas with intermediate values of 300 t 500 Btu/scf; and (3) gas of pipeline quality, similar in hea ing value to natural gas (950 to 1,000 Btu/scf). The var ous gasification processes now under development hav been described by Mudge et al. (1974), Hogland and A bury (1974), National Academy of Engineering (197 1973), and Seay et al. (1972).*

The amount of coal needed for coal conversion at an one plant site will vary, of course, with the plant's capacity the nature of the coal, and the efficiency of the process Most discussions in the literature relating to high-Btu gasif cation consider as a standard a plant with a capability o producing 250 million standard cubic feet per day (scfd) To produce gas of 950 Btu/scf from Illinois coal contain ing 11,260 Btu/lb (as-received basis) in a plant with 70 per cent thermal efficiency, 15,066 tons of coal per day woul be required to generate the 250 million scf. On that basis operation of a conversion plant for 335 days per year woul require 5,047,101 tons of coal. If the mines supplying th coal were to operate 250 days per year, a mine productio of 20,188 tons would be required daily. For a plant life o 30 years, 151.4 million tons of coal would be needed, requirement that would necessitate a coal reserve of abou 300 million tons in the ground if the recovery rate were 5 percent.

It is likely that such a large amount of coal would requir the output of two, or probably three, mines. It would b convenient to have these mines near the plant site, but eve then some transportation of the coal would be necessary.

To increase the heating value of the coal, coal prepara tion may be desirable to remove as much as practical of th

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* See references at end of Part 2.

* These references are given in the Bibliography of Part 1, und the heading "Coal Conversion."

eral matter, including sulfur, in the coal. Most of the
l now used in Illinois has had some preparation. The
posal of wastes resulting from coal preparation and of the
and other wastes remaining after coal conversion must
considered in planning a coal conversion plant, and the
thod of disposal must be environmentally acceptable.

Although no data based on practical experience are avail-
e regarding water requirements for commercial coal con-
sion operations, estimates of the requirements for the
ious processes indicate that conversion industries will be
jor users of water. Large quantities of water will be used
cooling and processing, and the water discharged will be
ered in physical state, mineral quality, and temperature.
to about 10 percent of the water will actually be con-
ned and must be replaced by make-up water. Most of
consumed water is returned to the atmosphere by evap-
tion from cooling towers and surfaces such as ponds. A
nificant portion is consumed to supply hydrogen for the
duction of hydrocarbons. The total water demands and
make-up water requirements are comparable to the
ter supplies required by large cities. The total water re-
irements of a coal conversion plant will depend largely
on the measures taken to conserve or recycle the water.
e maximum amount of water would be required by a
nt that used once-through circulation of water for
ling.

At the proposed WESCO plant of the Western Gasifica-
n Company (1973)* in New Mexico, where water re-
rces are limited, stringent efforts will be made to reduce
and to maximize reuse of water. The plans for this
nt probably involve a minimum of water consumption.
timated disposition of the water is given in table 1.

In our report, the availability of water resources for coal
nversion is evaluated on the basis of requirements for wa-
consumption or make-up water instead of on the total
ter need. It is assumed that coal conversion plants with
apacity of 250 million scfd of high-Btu synthetic natural
(SNG) will consume from 14 to 72 mgd of water,
t that, with extreme conservation measures, water con-
nption may be reduced to as low as 6 mgd. The levels of
ter consumption considered in this report are given in
le 2. Much the same amounts of water will be required
liquefaction of coal.

The quality of water required for coal conversion pro-
sses has not yet been determined. Water treatment is now
highly developed that raw water of almost any quality
n, by a combination of processes, be changed to a fin-
ed water that will meet almost any specifications. Nat-
ally, if the water is highly mineralized or highly polluted,
e treatment costs will be much higher than they would be
the water is relatively clean.

TABLE 1—WATER BUDGET FOR A LURGI COAL GASIFICATION PLANT

(Production 250 million standard cubic feet per day synthetic natural gas; after WESCO, 1973)

Disposition of water	gpm	Percentage of water used
PROCESS CONSUMPTION		
To supply hydrogen	1,120	
Produced as methanation by-product	−600	
Net consumption	520	10.2
RETURN TO ATMOSPHERE		
Evaporation:		
From raw water ponds	420	
From cooling tower	1,760	
From quenching hot ash	150	
From pelletizing sulfur	250	
From wetting of mine roads	730	
	3,310	
Stack gases:*		
From steam blowing of boiler tubes	200	
From stack gas SO_2 scrubbers	40	
	240	
Total return to atmosphere	3,550	69.6
DISPOSAL IN MINE		
In water treating sludges	100	
In wetted boiler ash	30	
In wetted gasifier ash	300	
Total disposal in mine	430	8.4
OTHER MEANS		
Retained in slurry pond	20	
Miscellaneous mine uses	580	
Total others	600	11.8
TOTAL	5,100	100.0

* *Does not include water derived from burning of boiler fuel.*

TABLE 2—RANGE IN WATER CONSUMED BY ONE COAL CONVERSION PLANT

(Production 250 million standard cubic feet per day of synthetic natural gas)

Level of use	gpm	cfs	mgd
Very low (extreme conservation measures)	4,000	9	6
Low	10,000	22	14
Medium	20,000	45	29
High (would use if readily available)	50,000	111	72

Reference appears in Reference list at end of Part 2.

Part 1. Coal Resources

William H. Smith

INTRODUCTION

The coal-bearing sequence of rocks in Illinois, formally termed the Pennsylvanian System, underlies about 65 percent of the state—36,806 out of a total of 56,400 square miles. The Herrin (No. 6) Coal Member, the thickest and most widespread coal in Illinois, as mapped in this study is 42 or more inches thick throughout an area of 9,269 square miles and has been mined out in an additional area of about 927 square miles. The Harrisburg-Springfield (No. 5) Coal Member, which is second in abundance, is 42 or more inches thick throughout 7,299 square miles and has been mined out in about 331 square miles.

The distribution, by thickness and tonnage, of an estimated total of approximately 97 billion tons of coal 42 or more inches thick in the Herrin and Harrisburg-Springfield seams is shown in the maps and tables of this report. Of this total, an estimated 59 billion tons are Herrin Coal and 38 billion tons are Harrisburg-Springfield Coal. The distribution of these reserves is shown on plates 1 and 2, in which the color used for each township symbolizes the estimated average tons of coal in place per square mile. Other maps and tables in the report and tables in Appendix 1 provide additional basic information on coal resources and geological factors relating to their minability and use, all of which should prove helpful in the siting of coal conversion facilities.

The inventory of Illinois coal reserves made in 1952 by the Illinois Geological Survey included coal in seams more than 28 inches thick and revealed an estimated 137 billion tons of coal in some 20 different seams. Subsequent studies by the Geological Survey, including a series of seven reports on strippable coal reserves in seams 18 or more inches thick and no more than 150 feet deep, increased the estimate of remaining reserves of coal to 147 billion tons, 71 percent of which was Herrin and Harrisburg-Springfield Coals. In this report additional reserves of approximately 14.7 billion tons have been mapped that were not included in previous studies. Estimated total coal reserves for Illinois mapped by the Geological Survey, therefore, have increased from 147 billion to 161.6 billion tons (fig. 1).

The data on reserves compiled in this report do not represent a complete re-evaluation of total coal resources in Illinois. Several areas in the state have other coal seams 42 or more inches thick, some of which may have large enough reserves to support several mines. Seams less than 42 inches have been strip mined in some places, particularly the Colchester (No. 2) Coal Member, which averages about 30 inches thick in several areas. Other seams containing coal 42 or more inches thick may be locally significant. It is possible that some Illinois coals thinner than 42 inches can be used to supply part of the coal needed for conversion plants but it is unlikely that sites primarily dependent on coals thinner than 42 inches will be selected.

The computer techniques developed for this study will facilitate any future re-evaluation of Illinois coal resources. Details of methods used in assembling and plotting data and in calculating reserves are given in Appendix 2.

This study has been the first to produce statewide maps from the ILLIMAP program developed in 1970 by D. H. Swann and others at the Illinois Geological Survey for computer mapping of geological information. The computer-graphics techniques used to calculate the coal resources inventory and to compute and plot the information displayed on the maps employ some new methods that are briefly described in Appendix 2.

The bibliography immediately following Part 1 is divided into six subject categories. Within each category the references appear in alphabetical order, but throughout the

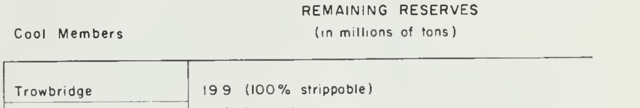

Figure 1. Remaining reserves of coal in place in Illinois, January 1, 1975.

TABLE 3—SUMMARY OF CLASSIFICATIONS FOR COAL RESERVES INVENTORY (Cady and others, 1952[28])

Class	Maximum distance from datum points*	Accepted datum points	Remarks
I-A Proved	½ mile	Mined-out areas Diamond drill holes Outcrops	Approximately equivalent to "measured" category of the U. S. Geological Survey
I-B Probable	2 miles	All points of Class I-A plus coal test churn drill holes	Approximately equivalent to "indicated" category of the U. S. Geological Survey
II-A Strongly indicated	4 miles	All points of Classes I-A and I-B plus churn drill holes drilled for oil or water with unusually good records and control rotary drill holes	Approximately equivalent to "inferred" category of the U. S. Geological Survey
II-B Weakly indicated	Indefinite	All points used in higher categories plus knowledge of geologic probability based on all available information	

* *Distances modified in practice by geological considerations.*

bibliography as a whole they are numbered consecutively, regardless of category. The text citations, therefore, consist of the author's name, the date of publication, and a superscript referring to the reference number in the bibliography—for example (Damberger, 1971[5]).

PREVIOUS INVESTIGATIONS

The comprehensive report on the minable coal reserves of Illinois published by the Geological Survey (Cady and others, 1952[28]) reviewed the estimates of coal reserves that had previously been made and established definitions and premises for the classification of coal reserves on the basis of the distribution and reliability of data. The definitions (table 3) have been followed, with some modifications, in subsequent reports of the Survey. When the present report was compiled, the work maps for the 1952 study provided the principal source of data for the two coal seams studied, and the classification of the reserves followed the basic premises and parameters that Cady had used, although information from more recent reports was incorporated. In addition, we used conventional electric logs of oil and gas wells to estimate coal thickness in certain areas where the data from coal test holes are scarce.

Strippable coal reserves were included in the 1952 report but were not differentiated from other coal reserves. In a series of reports published by the Geological Survey, beginning in 1957, strippable coal reserves were mapped at the scale of half an inch to the mile for most of the coal seams in Illinois that are strippable (fig. 2). In those reports, strippable coal, divided on the basis of quality of data into two categories of reliability of mapped reserves, was mapped by township and by 1-foot increments of coal thickness, beginning at 18 inches. Within each of these categories

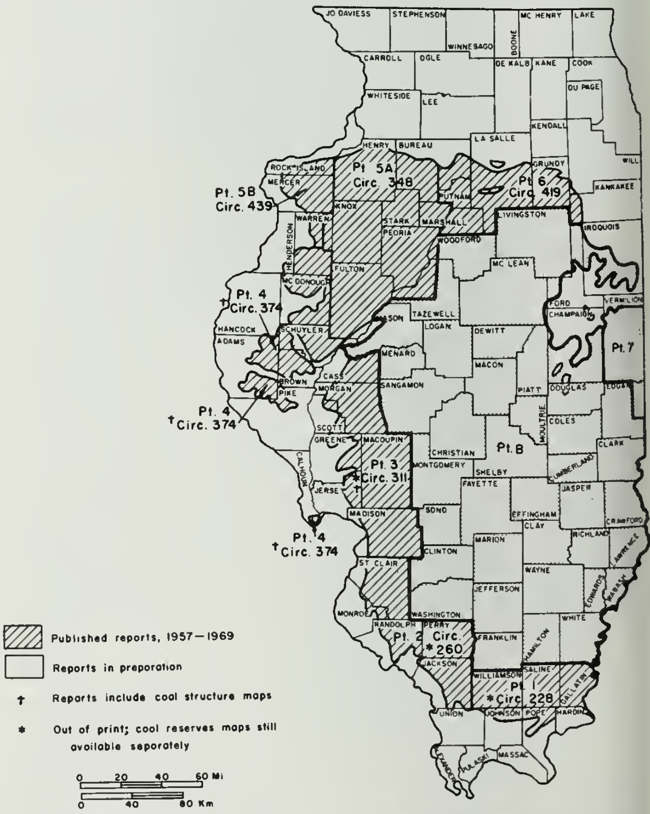

Figure 2. Index to reports on strippable coal reserves of Illinois.

e coal was divided into three classes on the basis of depth overburden—0 to 50 feet, 50 to 100 feet, and 100 to 150 et (Reinertsen, 1964[42]; Searight and Smith, 1969[43]; nith, 1957[45], 1958[46], 1961[47], 1968[48]; Smith and Bergen, 1963[49]).

In a series of Geological Survey reports dealing with subrface geology and coal resources of the Pennsylvanian 'stem in certain Illinois counties, the reserves mapped in e 1952 study were modified to include additional information and more detailed maps of the geology and strucre of the coal seams. These reports are listed under "Coal esources" in the bibliography to Part 1.

Coal reserves in several counties in southeastern Illinois ig. 3) have been mapped in recent years. Hopkins 968[37]) investigated the reserves of the Harrisburg Coal in utheastern Illinois, and his study was the first report pubhed by the Survey to use data from electric logs of oil and s test holes for mapping coal reserves. Since publication that report, much of the area for which reserves were apped has been leased and extensively drilled for coal. esults generally have confirmed the coal thickness intereted from the electric logs. In a similar report, Allgaier id Hopkins (1975[24]) mapped reserves for the Herrin Coal several southeastern Illinois counties (fig. 3).

DEFINITIONS AND METHODS

The quantities of coal estimated in this study are referred collectively as reserves and have not been further subvided, as they were in most previous studies. The term eserves" as used here refers broadly to coal deposits that, ised on interpretation of geologic information, are preimed with a reasonable degree of certainty to exist within coal seam. We have mapped and calculated only coal that 42 or more inches thick and could best meet the anticiited demands for large quantities of coal by coal converon plants. All new information relating to coal thickness id distribution that has been acquired since the inventory onducted by Cady and others (1952[28]) was added to the ita base used in the earlier study. Certain areas of coal, escribed later, have been excluded in making these timates.

In this report the estimates of coal reserves include coal ing within a maximum distance of 4 miles from the neart datum point (table 4). This definition encompasses all oal in the categories designated in the 1952 study as Class A *(proved)*, Class I-B *(probable)*, and Class II-A *(strongly dicated)* (table 3).

lassification of Reserves

The classification of reserves set up in the 1952 study was modified for this report (table 4) to place all coal reserves 42 or more inches thick in a single class. The single classification enabled us to handle the data more quickly and easily by the computer methods employed.

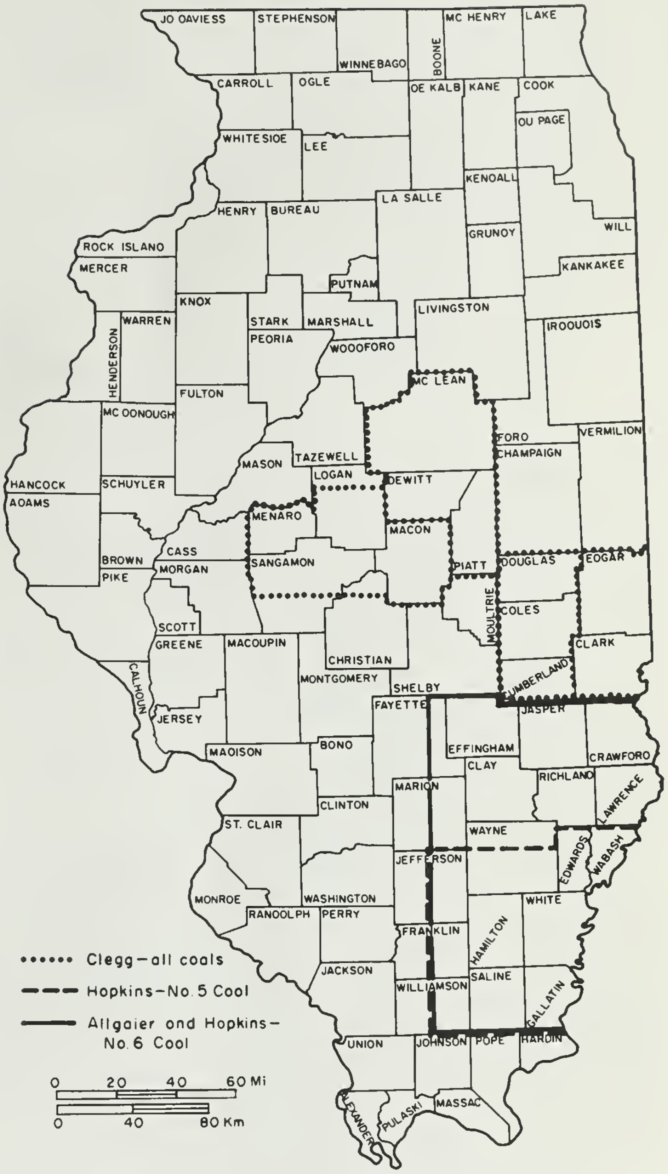

Figure 3. Index to area reports on coal reserves.

Figures 4 and 5 show areas with Class I reserves and Class II reserves. However, on plates 1 and 2 and in the reserves tabulation, only one class, combining Classes I and II, was used. For the Herrin Coal, approximately 73 percent of the areal extent of the estimated reserves is in Class I (Classes I-A and I-B of the 1952 study) and approximately 27 percent is in Class II (Class II-A of the 1952 study) (table 3). For the Harrisburg-Springfield Coal, approximately 49 percent of the area is in Class I, and about 51 percent is in Class II.

TABLE 4—CLASSIFICATION OF RESERVES MAPPED IN THIS REPORT

Class	Maximum distance from datum points	Accepted datum points	Remarks†
All coals included in a single class that incorporates Classes I-A, I-B, and II-A of Cady and others (1952[28]) and subsequent studies*	4 miles	All classes of data used in 1952 report plus interpretations of conventional electric logs of oil and gas drill holes in some areas	Only coal 42 or more inches thick included

* *Includes strippable coal 42 or more inches thick (total coal in ground with less than 150 feet of overburden).*

† *All volume calculations were based on coal having a specific gravity of 1.32, which is equivalent to 82.64 lb/cu ft. This is equivalent to 1,800 tons/acre-ft, or 1.152 million tons/sq mi-ft.*

Areas Excluded from Estimates of Reserves

Areas where the coal has been mined out or is missing because geologic features such as sandstone-filled channels are known to have disrupted its lateral extent have been excluded from the estimates of reserves. Plates 1 and 2 show mined-out areas for the Herrin and Harrisburg–Springfield Coals as they were on July 1, 1973. Areas overlying oil pools (closely drilled areas), shown on plates 1 and 2, also have been excluded. Not excluded, however, are areas of coal that may be unminable by virtue of their location under municipalities, highways, water impoundments, and other cultural features.

Areas of coal that overlie oil and gas pools and are closely drilled have been excluded from the estimates because current mining practices make it impractical to mine coal within such areas. The current Federal mining law prohibits the mining of coal within a radius of 150 feet around oil wells unless adequate well plugging ensures safe conditions with smaller coal pillars. Well spacing within the excluded areas shown on plates 1 and 2 generally is 660 feet (one well per 10 acres), but mining under such conditions is generally uneconomic.

Only the oil and gas wells within pool areas, shown in gray on plates 1 and 2, have been excluded. In the many single wells scattered throughout the coal fields, a pillar of coal 300 feet in diameter (in some cases smaller pillars) must be left around the well, but the unrecoverable coal around these wells could not accurately be deleted from our calculation of reserves.

Areas in which coal is thin and areas for which insufficient information is available for mapping classified reserves also were excluded from the reserves (pls. 1 and 2), as were the areas adjacent to some of the sandstone channels where the coal is known to be split by partings of shale or sandstone that generally make the coal unminable by underground mining methods. All of the sandstone-channel and split-coal areas that are known within the two coal seams are indicated on plates 1 and 2 and are described later in more detail.

Acknowledgments

The author is indebted to M. E. Hopkins, Head of the Geological Survey Coal Section, for assistance in the administration of the project and for his help in editing the manuscript and maps. Lawrence E. Bengal was responsible for much of the planning and execution of the mapping, and Russell J. Jacobson assisted in compilation of the reserves estimates, which were drawn from the work of many past and present members of the staff of the Geological Survey Coal Section.

J. P. Hoeflinger of the Computer Services Section of the Geological Survey coordinated computer programming and processing of the data in cooperation with other members of this unit. Assistance in computer mathematics and programming were provided by William G. Miller. L. Michael Kaas and Paul M. Juneman of International Business Machines Corporation supplied information about the STAMPEDE computer program and its application to the mapping techniques used in this study. Illustrations for Part 1 were prepared by Marie L. Martin, Sue-Ann Meyer, and Patricia A. Whelan. The manuscript was edited by Betty Lynch.

ESTIMATED COAL RESERVES

Estimated coal reserves 42 or more inches thick totaling 97 billion tons have been mapped for the Herrin (No. 6) Coal and the Harrisburg–Springfield (No. 5) Coal. Their thickness ranges from the 42-inch minimum established for this study to more than 10 feet. The total coal in the ground in that thickness range is shown in table 5. Average thickness of the Herrin Coal is 5.52 feet, and 56 percent of the mapped reserves of this coal is 6 feet or more thick. The Harrisburg–Springfield Coal averages 4.55 feet thick, and 47 percent of its mapped reserves is 5 feet or more thick (table 5).

The distribution of these reserves for each county is given in table A (Appendix 1) by 1-foot increments of thickness, beginning at 4 feet. Table A also shows for each of

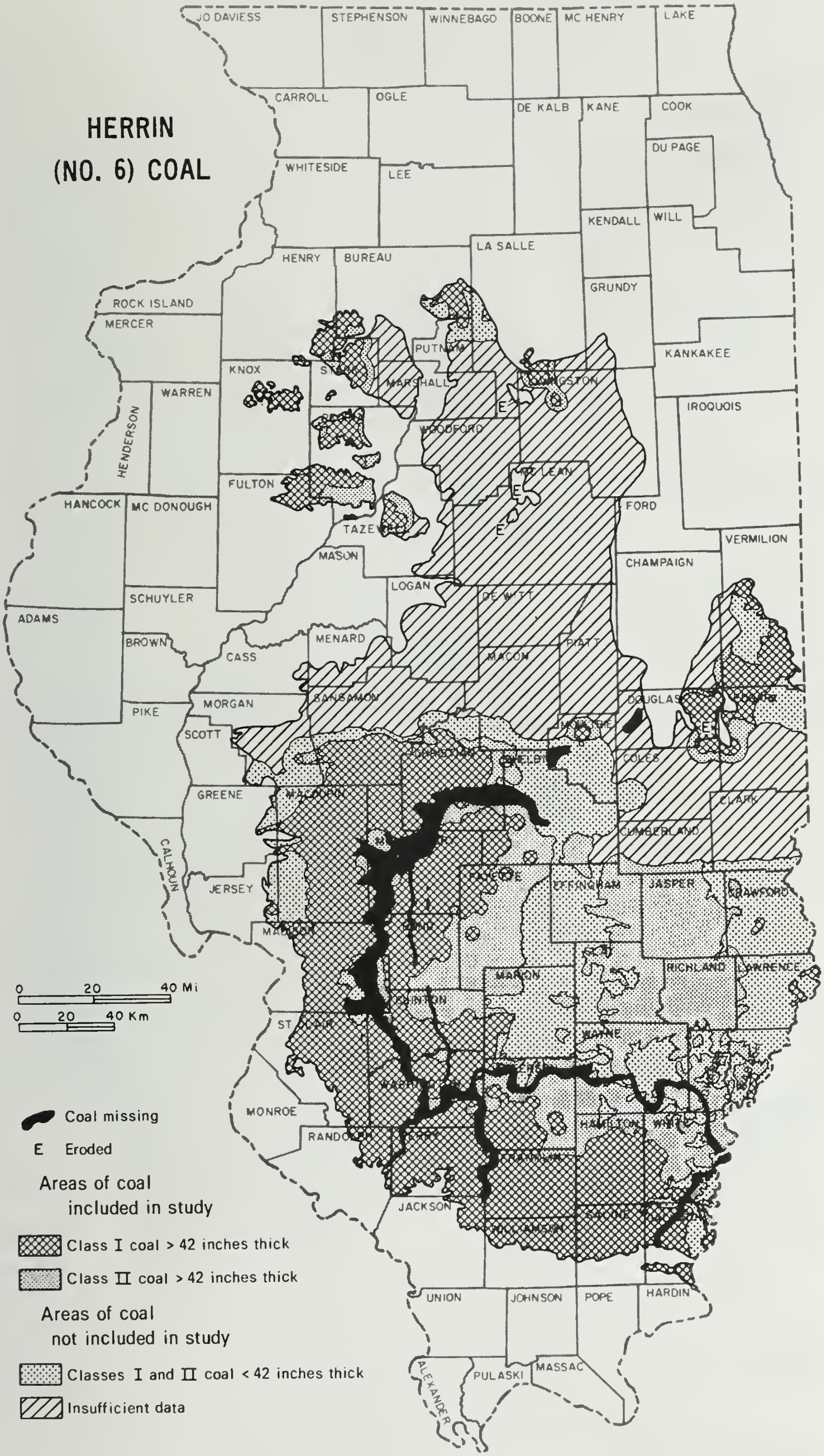

Figure 4. Classification of Herrin Coal reserves. Classes are defined in tables 3 and 4.

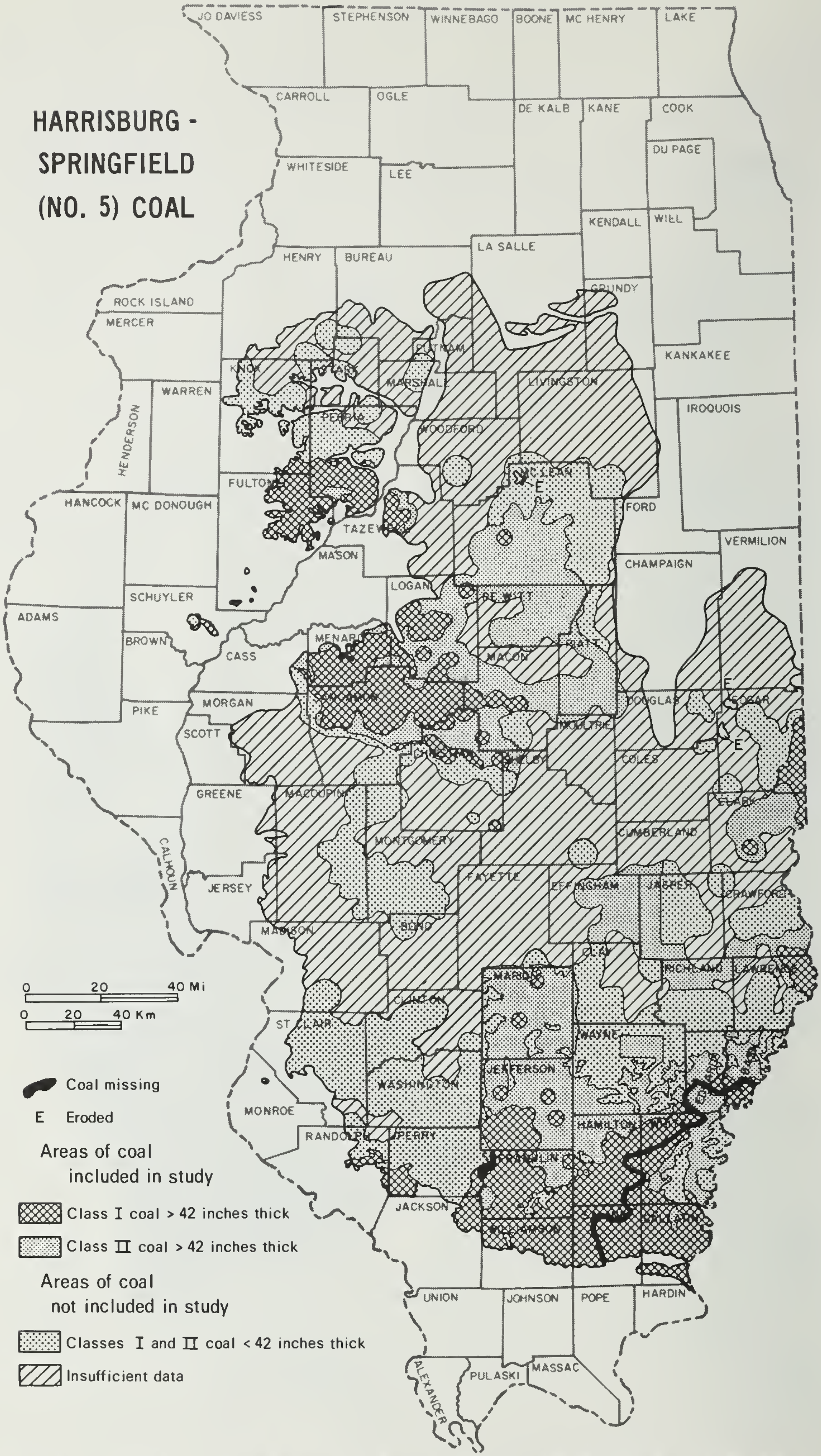

Figure 5. Classification of Harrisburg-Springfield Coal reserves. Classes are defined in tables 3 and 4.

TABLE 5—SUMMARY OF COAL RESERVES

By thickness of seams

Average* thickness of seam (ft)	Herrin (No. 6)		Harrisburg-Springfield (No. 5)		Total remaining reserves	
	Thousands of tons	% of sub-total	Thousands of tons	% of sub-total	Sub-total (thousands of tons)	% of grand total
4	13,300,102	22.6	20,261,331	53.0	33,561,433	34.5
5	12,657,243	21.5	11,321,567	29.6	23,978,810	24.7
6	12,290,311	20.8	5,572,030	14.6	17,862,341	18.4
7	11,586,777	19.7	806,097	2.1	12,392,874	12.7
8	7,831,170	13.3	249,413	0.6	8,080,583	8.3
9	1,018,906	1.7	24,485	0.07	1,043,391	1.1
10	256,668	0.4	9,677	0.03	266,345	0.3
Totals	58,941,177	100	38,244,600	100	Grand total: 97,185,777	100

By area†

Category	Herrin (No. 6)		Harrisburg-Springfield (No. 5)		Total remaining reserves	
	Sq mi	% of original reserves	Sq mi	% of original reserves	Sub-total (sq mi)	% of original reserves
Original reserves	10,196	100	7,630	100	17,826	100
Mined out	927	9.1	331	4.3	1,258	7.1
Remaining reserves	9,269	90.9	7,299	95.7	16,567	92.9

* *The average thickness of all remaining reserves in the Herrin seam is 5.52 feet and in the Harrisburg-Springfield seam 4.55 feet.*

† *Because the areas underlain by the No. 5 and No. 6 seams overlap in part, this represents areas of unmined coal and should not be confused with surface area.*

e two coal seams the total area of each county that is nderlain by reserves. Also listed in the table are the area coal mined out from each of the seams, by county, the eighted average thickness of all of the remaining coal in ch seam, and the weighted average tons of remaining coal r square mile.

Plates 1 and 2 show the average tons of coal 42 or more ches thick remaining in place per square mile in each town-ip. The maps enable comparison of the amount of coal serves in one area with reserves in other areas. The re-rves can also be related to a variety of geologic features at influence the thickness and distribution of the coal.

GEOLOGY OF THE COAL SEAMS

egional Relations

Illinois has greater reserves of bituminous coal than any ther state. Figure 6 shows the distribution of coal fields in e United States, and Appendix table B and figure 7 com-are the demonstrated coal reserves of Illinois with those of ther coal-producing states. The data in table B and figure are from a recent tabulation by the U.S. Bureau of Mines. ecause of differences in criteria used in classification, the ureau of Mines figures for Illinois are substantially lower than those shown in the other maps and tables of this report.

The coal fields of Illinois lie within the Eastern Region of the Interior Coal Province, which is commonly called the Eastern Interior Coal Field (fig. 8). The coals lie with-

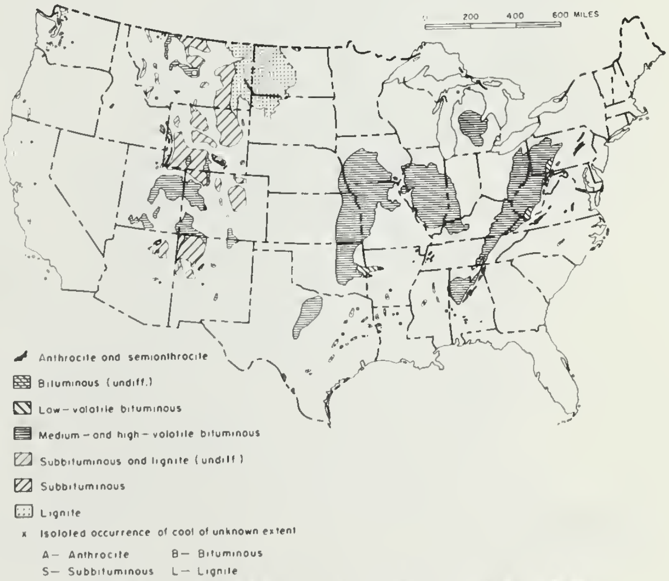
0 200 400 600 MILES
Anthracite and semianthracite
Bituminous (undiff.)
Low-volatile bituminous
Medium- and high-volatile bituminous
Subbituminous and lignite (undiff.)
Subbituminous
Lignite
x Isolated occurrence of coal of unknown extent
A— Anthracite B— Bituminous
S— Subbituminous L— Lignite

Figure 6. Coal fields of the contiguous United States.

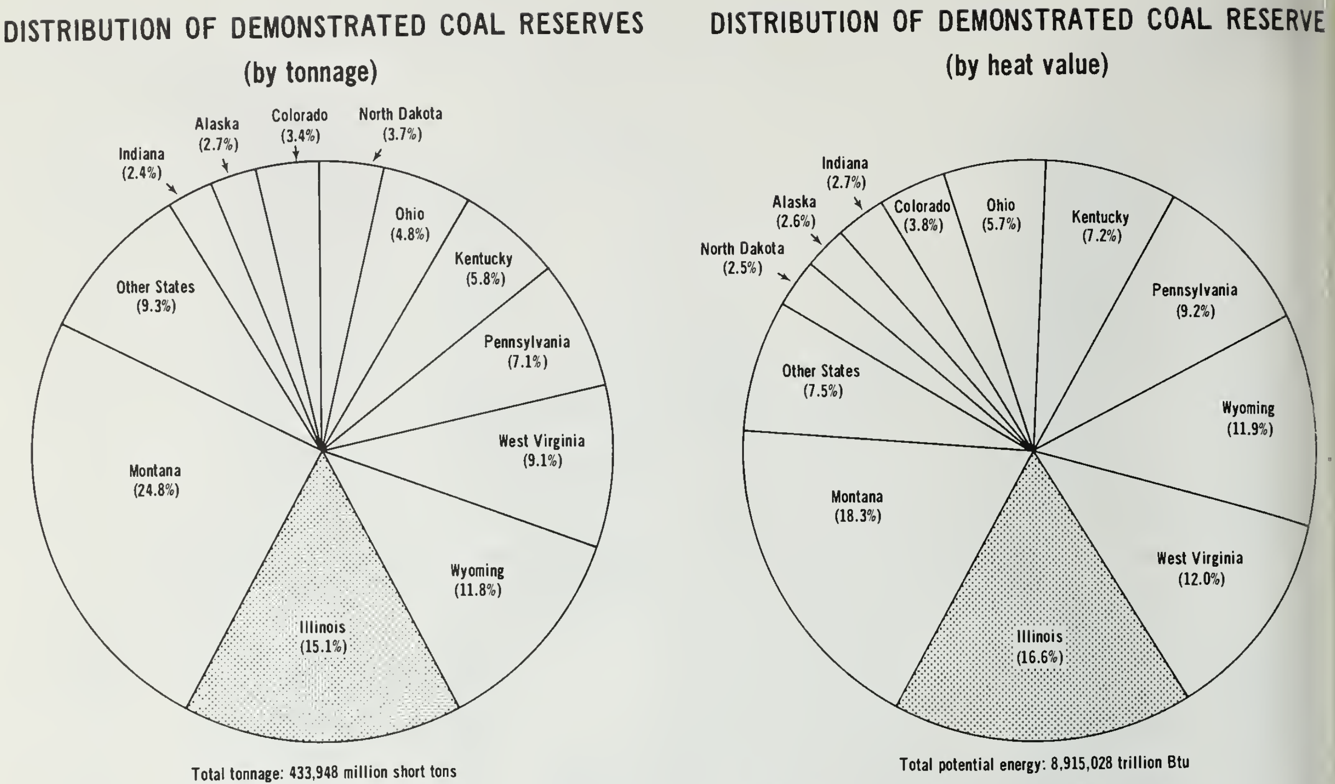

Figure 7. Demonstrated coal reserves base of the United States and estimated energy potentials by state. (Data from U.S. Bureau of Mines, 1974[51]; Library of Congress Congressional Research Service, 1973[56]. Prepared by Ramesh Malhotra, Mineral Economics Group, Illinois Geological Survey.)

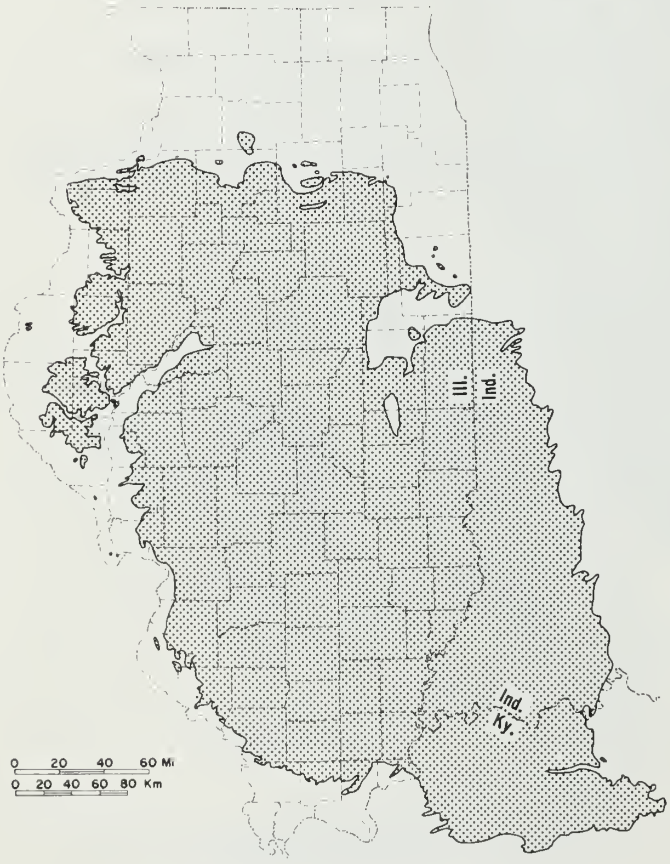

Figure 8. Eastern Interior Coal Field.

in a structural depression called the Illinois Basin (fig. 9) the position of which approximately coincides with that o the Eastern Interior Coal Field.

Within the Illinois Basin are numerous structural features, such as anticlines, synclines, and faults, that locall influence the dip, thickness, and continuity of the coa seams. The major geologic structures are shown in figure 9 The structure of the Herrin Coal and of some areas of th Harrisburg-Springfield Coal has been mapped on scales o 1 inch to the mile and half an inch to the mile for a substantial part of the Illinois coal fields.

The Herrin and Harrisburg-Springfield Coals occur nea the middle of the stratigraphic sequence of Pennsylvania rocks (fig. 10). They are separated by an interval rangin from 10 feet or less at some places in western and centra Illinois to more than 120 feet in southeastern Illinois (fi 20). The coals crop out toward the margins of the Illino Basin, and in the deepest part of the basin they attain maximum depth of more than 1,200 feet (figs. 15 and 17)

The regional thickness of the coals is indicated by colo on plates 1 and 2. Two major geological influences affecte their regional thickness. First, on some prominent stru tures (fig. 9) very little coal was deposited because of the topographic influence on the depositional surface. Secon major drainage systems in the swamps promoted a mo abundant accumulation of coal-forming vegetation in th vicinity of the principal channels. However, no plant mat rial accumulated in the drainageways, and they were su

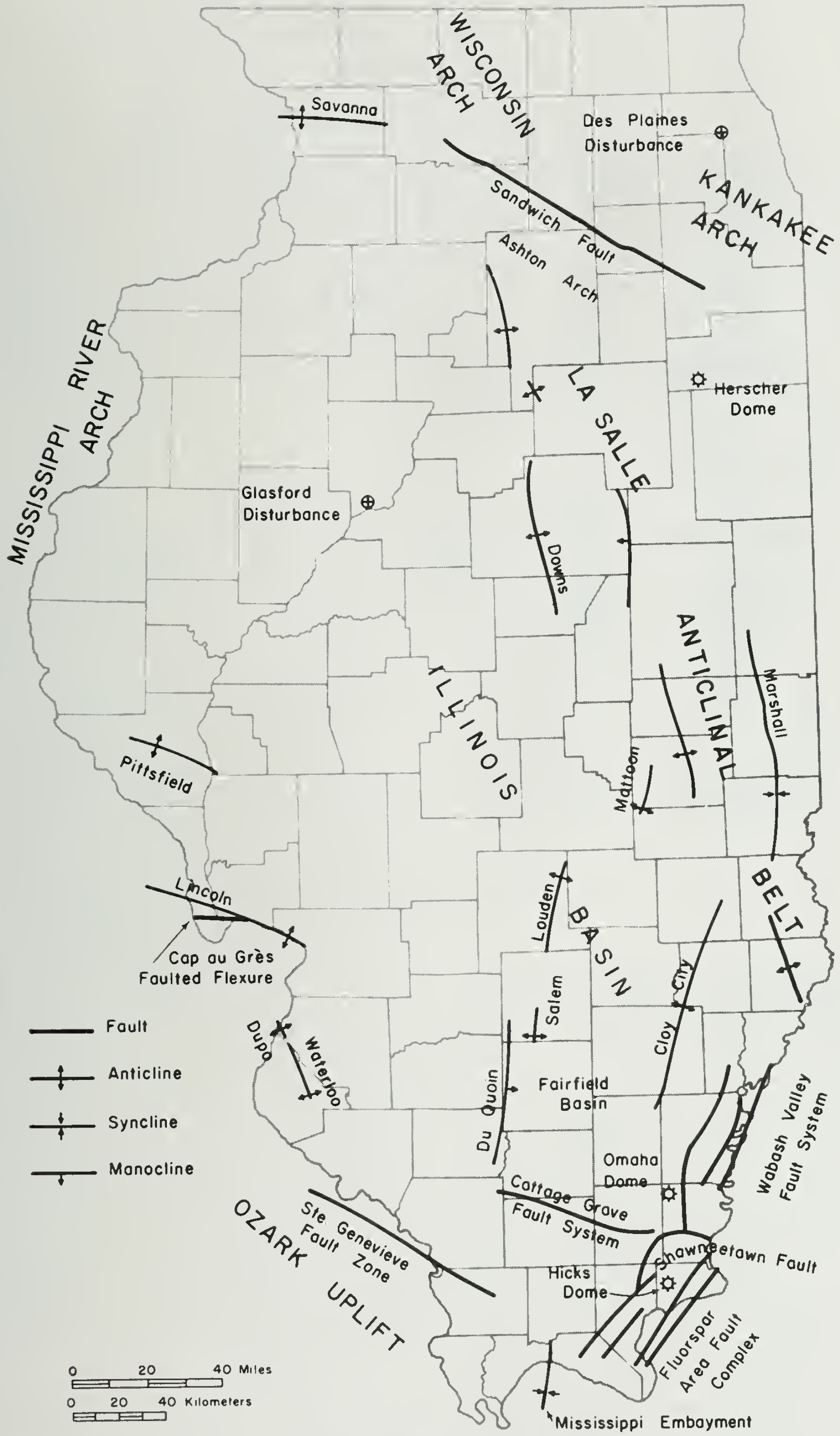

Figure 9. Geologic structures of Illinois.

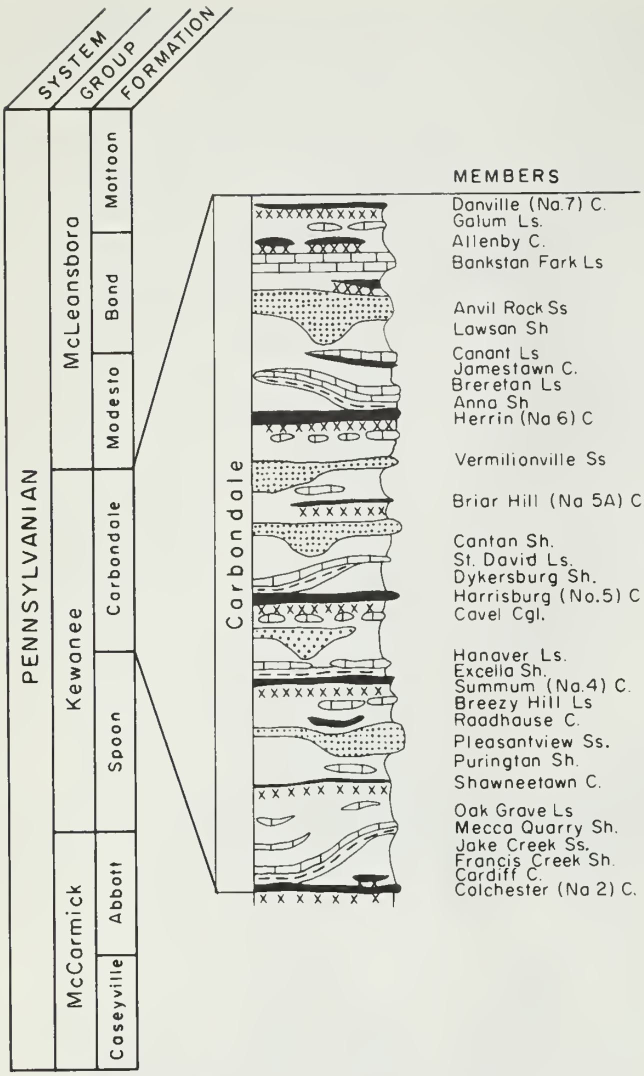

Figure 10. The stratigraphic section shows the position of the Herrin and Harrisburg-Springfield Coals within the Pennsylvanian System in Illinois.

sequently filled with sand or mud and became the sandstone or shale channels of the present coal seams.

The long, sinuous features shown in yellow on plates 1 and 2 mark the location of the former stream channels. Interlamination of coal with stream-laid silt and clay at the margins of some of the ancient streams makes it evident that these channels were contemporaneous with the coal swamp. Along the main axes of these channels, thick deposits of sandstone commonly occur and the coal is absent. Later, after the coal had formed and been buried by various layers of sediments, a new system of channels cut through the normal sequence of overlying strata, and in some places also eroded the coal. Like the contemporaneous channels, these later channels eventually filled with sand or mud. Both types of buried stream deposits are referred to on plates 1 and 2 as sandstone channels. Their occurrence is described in greater detail in the discussion of the geology of the specific coal seams, and their effect on coal mining is described in the discussion of minability of the coal seams.

The Geological Survey has made several studies of the distribution of sandstone channels that disrupt the coal. Hopkins (1958[66]) was the first to map in detail part of the Anvil Rock Sandstone Member, tracing its distribution in southern Illinois. Potter and Simon (1961[70]) mapped the sandstone channels in west-central Illinois, which Johnson (1972[67]) treated in greater detail. Hopkins (1968[37]) also mapped a prominent channel in the Harrisburg–Springfield Coal in southeastern Illinois and related it and associated strata to low-sulfur coal deposits in the area.

Quality of the Coals

The Geological Survey has long conducted a variety of studies relating to the quality of coal. Recently much of the research has involved the potential reduction of the sulfur content of Illinois coals by washing (Helfinstine et al., 1971[10], 1974[9]) and the occurrence of mineral matter and trace elements in the coal (Rao and Gluskoter, 1973[13]; Ruch, Gluskoter, and Shimp, 1974[15]).

The coal of the Herrin and Harrisburg–Springfield seams is of high-volatile bituminous rank, defined by standards of the American Society for Testing and Materials (ASTM) (table 6). Illinois coals are of high-volatile C rank in the northern part of the state, undergo a progressive increase in rank southeastward, and reach high-volatile A rank near the southeastern margin of the coal (fig. 11). The progressive increase in rank with original depth of burial has been described by Damberger (1971[5]) as a fundamental relation found in coal basins throughout the world. The greater the original depth of burial, the greater the degree of coalification and the higher the rank of the coal. In figure 11 the iso-rank lines for the Herrin Coal closely parallel the structure lines, except in southernmost Illinois where the rank increases fairly rapidly southward but where the coals crop out at or near the present land surface. There the original coalification pattern may have been modified by heat released from a deep-seated intrusion of igneous rocks. However, a more likely reason for the higher rank in the southeast is the area's proximity to the deepest part of the basin during the Pennsylvanian and Permian Periods, when coalification presumably took place.

The heating value of Illinois coal undergoes a progressive increase (fig. 11) from about 10,500 Btu/lb (moist mineral-matter free) in northwestern Illinois to over 14,000 Btu/lb in southeastern Illinois. Table 7 shows the range of typical analyses of the Herrin (No. 6) and the Harrisburg–Springfield (No. 5) Coals from various areas of the Illinois coal fields.

TABLE 6—CLASSIFICATION OF COALS BY RANK*

(from ASTM, 1973[1])

Class	Group	Fixed carbon limits (%) (dry mineral-matter-free basis)		Volatile matter limits (%) (dry mineral-matter-free basis)		Calorific value limits (Btu/lb) (moist† mineral-matter-free basis)		Agglomerating character
		Equal or greater than	Less than	Greater than	Equal or less than	Equal or greater than	Less than	
I. Anthracitic	1. Meta-anthracite	98			2			Nonagglomerating
	2. Anthracite	92	98	2	8			
	3. Semianthracite‡	86	92	8	14			
II. Bituminous	1. Low-volatile bituminous coal	78	86	14	22			Commonly agglomerating††
	2. Medium-volatile bituminous coal	69	78	22	31			
	3. High-volatile *A* bituminous coal		69	31		14,000**		
	4. High-volatile *B* bituminous coal					13,000**	14,000	
	5. High-volatile *C* bituminous coal					11,500	13,000	
						10,500	11,500	Agglomerating
III. Subbituminous	1. Subbituminous *A* coal					10,500	11,500	Nonagglomerating
	2. Subbituminous *B* coal					9,500	10,500	
	3. Subbituminous *C* coal					8,300	9,500	
IV. Lignitic	1. Lignite *A*					6,300	8,300	
	2. Lignite *B*						6,300	

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* *This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which come within the limits of fixed carbon or calorific value of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48 percent dry, mineral-matter-free fixed carbon or have more than 15,500 moist, mineral-matter-free British thermal units per pound.*

† *Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.*

‡ *If agglomerating, classify in low-volatile group of the bituminous class.*

** *Coals having 69 percent or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.*

†† *It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and there are notable exceptions in high-volatile C bituminous group.*

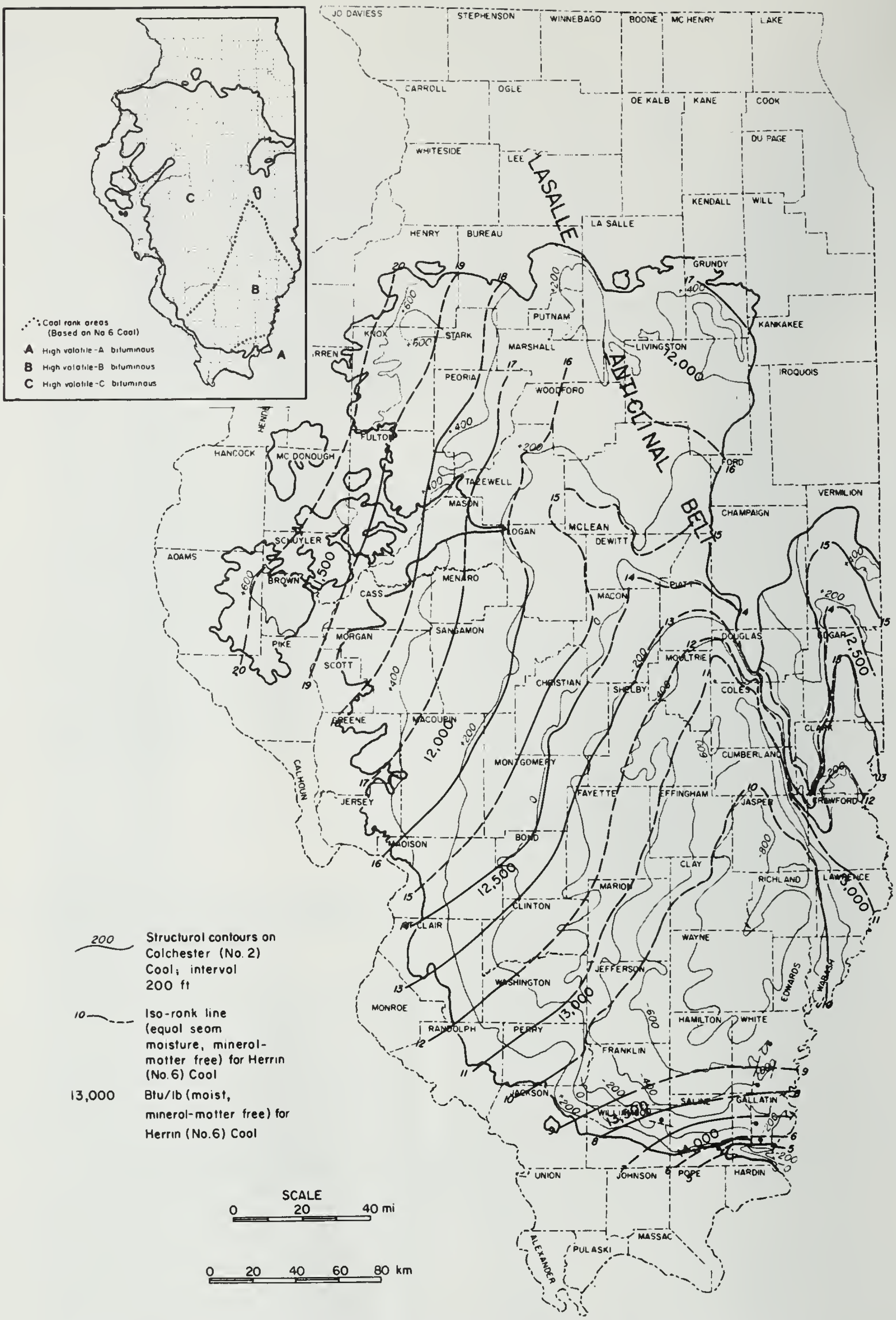


Figure 11. Coalification pattern in Illinois shows progressive increase in rank in the Herrin Coal southward (after Damberger, 1971[5]).

TABLE 7—RANGE OF TYPICAL ANALYSES BY COUNTIES*

County	As-received basis							
	Moisture (%)	Volatile matter (%)	Fixed carbon (%)	Ash (%)	Sulfur (%)	Btu/lb	Rank index†	Ash fusion (°F)
				HERRIN (No. 6) COAL				
La Salle, Grundy	13–16	36–41	35–40	7–11	3–5	10,500–11,400	116–123	1,950–2,150
Bureau, Stark, Henry, Knox	16–20	31–35	37–40	8–13	3–5	9,700–10,300	111–118	1,900–2,120
Peoria, Fulton	15–19	32–35	37–43	8–13	2–4	9,800–10,700	111–120	
Sangamon, Macoupin	12–16	35–40	37–41	9–11	3–5	10,400–10,900	116–123	1,930–2,160
Christian, Montgomery, Bond, Madison	12–14	35–40	38–41	9–11	3–5	10,500–11,000	117–125	1,920–2,170
Vermilion	14–16	32–36	38–41	8–12	1–3	10,400–11,100	118–128	2,080–2,220
Clinton, St. Clair	10–13	35–40	37–42	9–12	1–4	10,700–11,100	121–129	1,920–2,090
Marion, Washington, Randolph, Perry	8–12	35–39	38–44	9–13	1–4	10,800–11,300	124–133	1,920–2,610
Jefferson, Franklin, Jackson	7–10	32–37	45–50	7–10	1–3	11,600–12,000	130–135	1,920–2,650
White, Saline, Williamson	4–9	30–36	46–52	7–10	1–3	11,700–12,300	130–141	1,950–2,430
Gallatin (Eagle Valley)	3–5	32–35	46–50	10–13	3–4	12,400–12,700	138–147	
				HARRISBURG-SPRINGFIELD (No. 5) COAL				
Peoria, Fulton, Tazewell, Schuyler	14–18	33–38	34–40	9–12	2–4	10,100–10,800	115–122	1,890–2,270
McLean, Logan, Menard, Sangamon	13–17	34–39	36–41	9–12	3–5	10,400–11,000	117–125	1,890–2,060
Macon, Shelby	12–16	34–39	35–40	8–12	3–4	10,500–11,100	119–127	
Edgar	10–12	36–40	37–43	8–10	3–4	11,200–11,500	126–130	
Randolph, Perry	8–13	35–38	40–44	9–12	4–5	11,000–11,400	124–135	
Jackson	8–9	35–36	44–55	11	3–4	11,600–11,800	130–135	2,168–2,174
Gallatin, Saline, Williamson	5–7	33–38	47–53	8–12	2–5	11,900–12,500	132–141	1,940–2,010
Gallatin (Eagle Valley)	4–5	34–37	48–52	10–11	3–4	12,400–12,700	130–147	2,040–2,090

* *Adapted from data compiled by H. H. Damberger from Cady (1935[3], 1948[4]) and from coal analyses by the Illinois Geological Survey since 1948.*

† *Calorific value of moist coal on a mineral-matter-free basis to the nearest 100 Btu/lb.*

Sulfur Content

About 4 percent of the total reserves of the Herrin and Harrisburg-Springfield Coals is low-sulfur coal (less than 2.5 percent sulfur), as is shown in figures 12 and 13. In most of the Eastern Interior Coal Field, the coals are overlain by black shale and/or limestone, and the sulfur content normally ranges from 3 to 5 percent. However, in certain areas near sandstone-filled channels (figs. 12 and 13), gray silty shale intervenes between the coal and the overlying black shale and limestone. In areas where the gray shale deposits (which are considered to be genetically related to the sandstone channels) exceed 20 feet thick (figs. 14 and 16), the sulfur content of the coal is normally less than 2.5 percent.

The fact that most Illinois coal contains from 3 to 5 percent sulfur has been responsible for curtailment of its use to observe environmental restrictions. Development of new mines has therefore been greatly retarded. Studies conducted in recent years at the Geological Survey to evaluate and characterize the distribution of sulfur in Illinois coals have shown that sulfur content of Illinois coals ranges between 0.5 and 6.0 percent (dry basis), the average total sulfur content being about 3.5 percent (Gluskoter and Simon, 1968[7]).

Because the low-sulfur coal meets the standards for use in blends for manufacture of metallurgical coke, a significant part of the current production is used for this purpose. In 1972, the latest year for which figures are available, 4.4 million tons of Illinois coal was consumed in coke plants.

HERRIN (NO. 6) COAL MEMBER

The Herrin (No. 6) Coal Member, the most extensively mined coal in Illinois, was named for exposures near Herrin, Williamson County (Shaw and Savage, 1912[72]). It is correlated with the No. 11 Coal of western Kentucky, the Herrin Coal Member of Indiana, the Mystic Coal of Iowa, and the Lexington Coal of Missouri and Kansas. As shown on plate 1, it is 42 or more inches thick in an area covering 9,269 square miles in Illinois. It has been and currently is being strip mined along much of the southern and western margins of the Illinois Basin. Underground mining has been most extensive in areas where the coal is thickest and can be reached at moderate depths (generally 700 feet or less), but in Franklin and Jefferson Counties coal having lower than average sulfur content has been extensively mined at depths of as much as 800 feet. Of the total coal production in Illinois in 1973 (61.5 million tons), 75 percent was from the Herrin seam. Of the original area of 10,196 square miles mapped in this study for Herrin Coal reserves, 927 square miles have been mined out. The remaining in-place reserves of Herrin Coal 42 or more inches thick are estimated at 59 billion tons. The distribution of reserves by county appears in table A.

Thickness of the Coal

The Herrin Coal is the most widely mapped and thickest coal in Illinois, and it has been mined more extensively than any other seam. Mapping for this study revealed that the weighted average thickness of all coal 42 or more inches thick in the Herrin seam is 5.51 feet. Figure 14 shows the generalized thickness of the Herrin Coal, drawn from the data used for compilation of plate 1.

The Herrin Coal is absent where the Walshville Channel occurs (fig. 14). Along the margins of the channel the coal is generally split by sandstone or shale and may be unminable because it lies in relatively thin benches. On both sides of the channel and beyond the area of split or thin coal, the thickest coal is generally found.

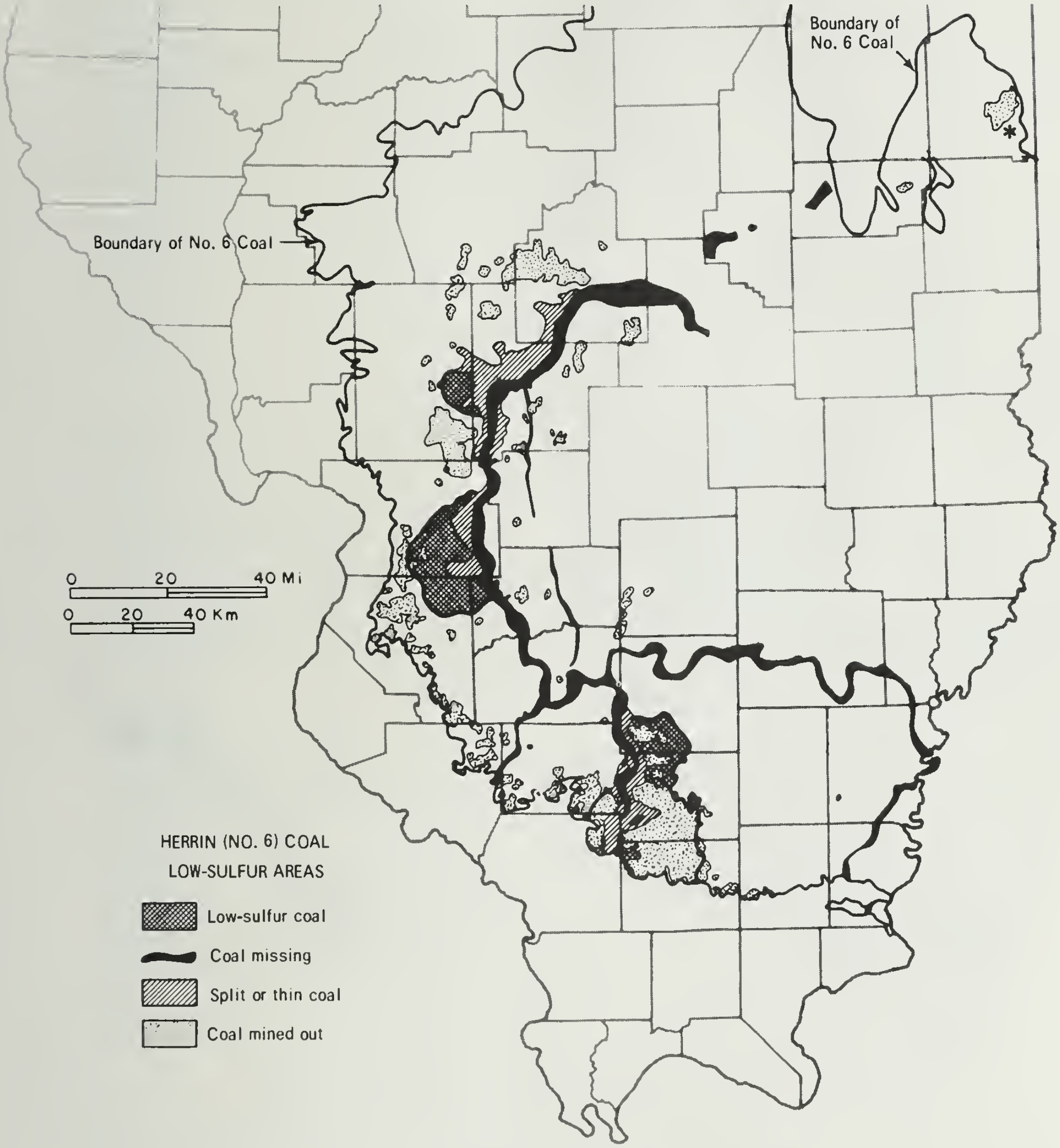
Regions in which the coal is thin (fig. 14) are those in which conditions for coal accumulation were not favorable. In several such regions geologic structures (fig. 9) appear to have been responsible. The area of thin coal in eastern Fayette County, western Effingham County, and central and northern Marion County reflects the Salem and Louden Anticlines, apparently high places in the coal swamps on which relatively little coal material was deposited. The abrupt thinning of the Herrin Coal northward from central Sangamon County and northern Christian County and a corresponding thickening of the Harrisburg-Springfield Coal in the same direction also may have been influenced by regional structure. The effect of the La Salle Anticlinal Belt and other large structural features on coal thickness suggests that most coal seams, including the Herrin Coal, become thin over positive structures and thick over negative structures, although this conclusion does not always apply.

Definition of the reserves of the Herrin Coal in north-central and east-central Illinois has been hampered by lack of sufficient data. In east-central Illinois Clegg (1959[30], 1965[32]) (fig. 3) mapped the structure of the Herrin Coal in Cumberland, Coles, Douglas, Clark, and Edgar Counties but did not modify reserves estimated by Cady and others (1952[28]) because no additional coal tests were available to indicate the thickness of the coal. Clegg (1965[32]) did, however, modify the coal correlations of the 1952 study by pointing out that the coal that was mapped as Danville (No. 7) Coal, which is being mined at Murdock, Douglas County, should have been correlated with the Herrin Coal. Therefore, substantial reserves in those counties formerly classified as the Danville Coal are mapped in this study as Herrin (No. 6) Coal.

Allgaier and Hopkins (1975[24]) mapped the thickness and estimated the reserves of Herrin Coal (fig. 3) in southeastern Illinois. They derived data primarily from electric logs of

ILLINOIS LOW-SULFUR RESERVES IN GROUND

Coal	County	Millions of tons
Herrin (No. 6) (< 2.5% S, av. 1.5%, dry basis)	Clinton	23
	Franklin	228
	Jackson	37
	Jefferson	469
	Macoupin	396
	Madison	245
	Perry	35
	St. Clair	381
	Williamson	59
		1,873



* Low sulfur reported in several of these mines.

Figure 12. Occurrence of low-sulfur coal in the Herrin seam.

ILLINOIS LOW-SULFUR RESERVES IN GROUND

Coal	County	Millions of tons
Harrisburg-Springfield (No. 5) (<2.5% S, av. ~ 2%, dry basis)	Edwards	54
	Franklin	243
	Hamilton	563
	Saline	627
	Wabash	262
	Wayne	89
	White	626
	Williamson	274
		2,738

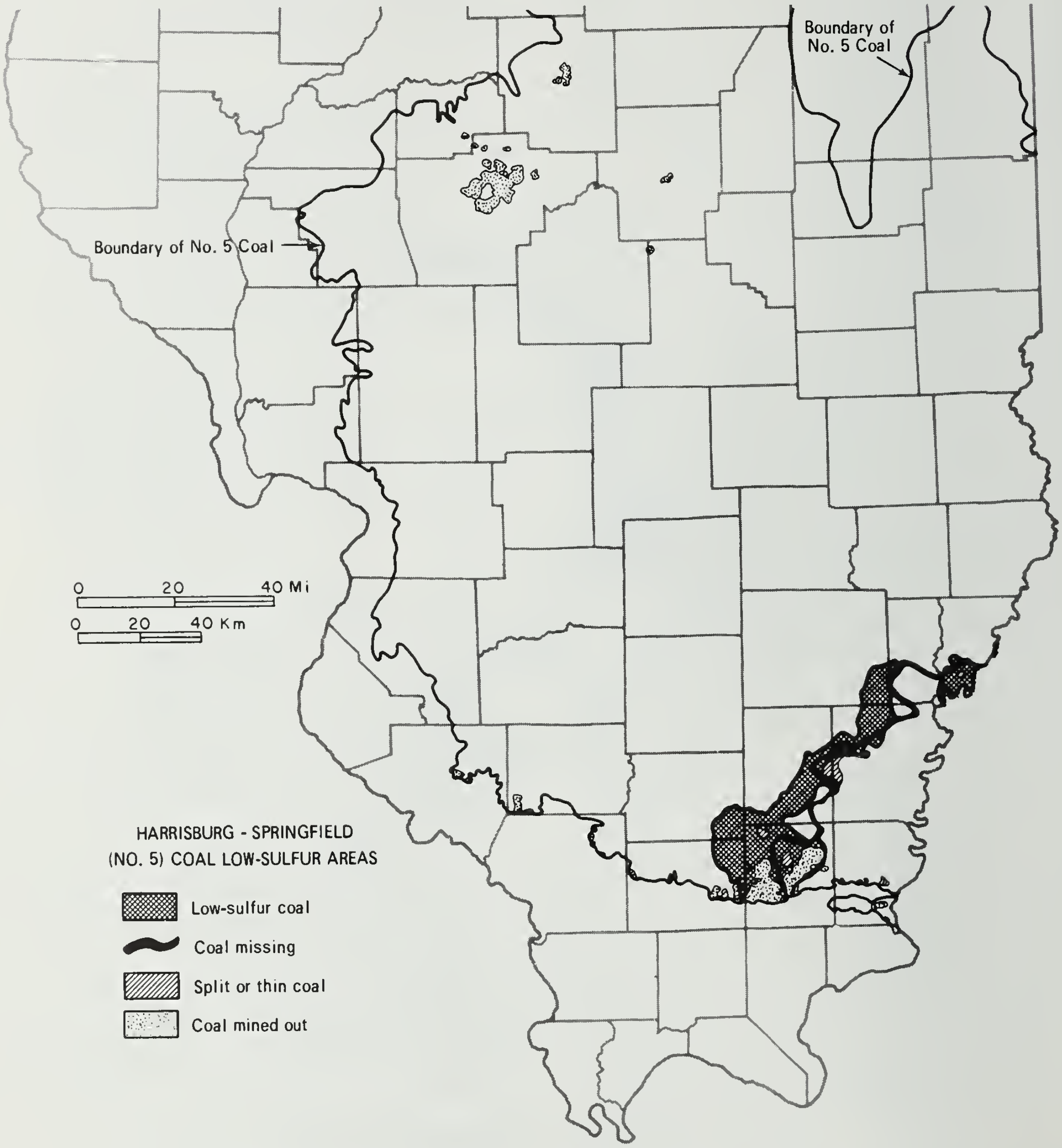


Figure 13. Occurrence of low-sulfur coal in the Harrisburg–Springfield seam.

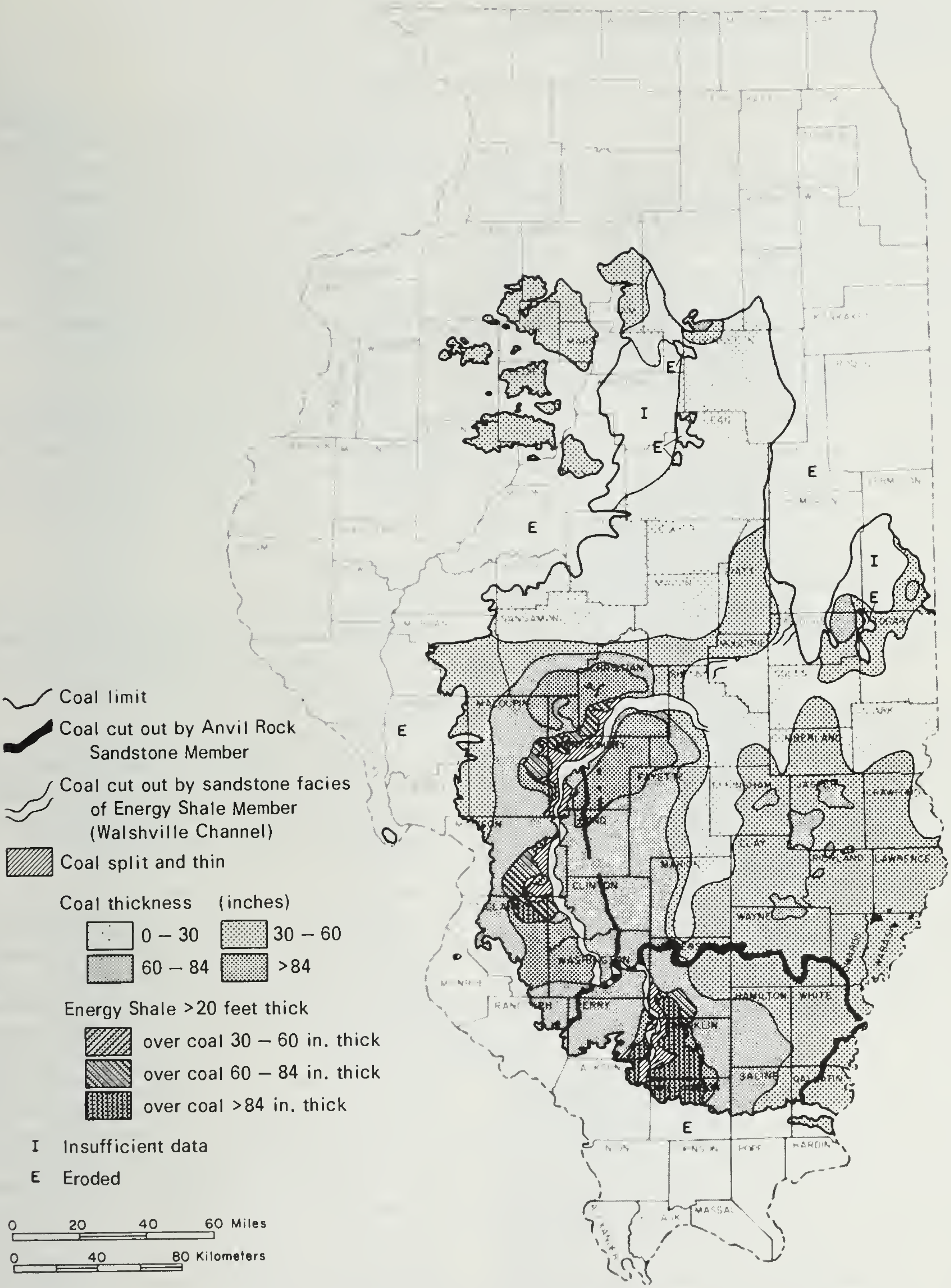


Figure 14. Generalized thickness of Herrin Coal.

oil wells and used them to interpret the coal thickness, as Hopkins (1968[37]) had done previously for the Harrisburg-Springfield Coal in much of the same region.

Depth of the Coal

The areas where the Herrin Coal is strippable lie toward the margins of the Illinois Basin; coal depth increases to a known maximum of 1,248 feet in Jasper County, near the center of the basin (fig. 15). The 150-foot depth line is shown on plate 1 to designate areas where the coal may be potentially strippable. Strippable areas of the Herrin Coal have been mapped in a series of reports (numbers 42, 43, 45, 46, 47, 48, 49 in the Bibliography) located geographically in figure 2. The strippable reserves of Herrin Coal by counties covered in that series of reports are summarized in table 8.

A comparison of the depth of the Herrin Coal throughout Illinois (fig. 15) with the overburden line on plate 1 shows that, fortunately, where the coal is thickest it also happens to be at moderate depth. None of the Herrin Coal lies deep enough to make it economically prohibitive to mine, and the availability of large volumes of thick coal at moderate depth may make it unnecessary at present to mine the coal in the deepest parts of the Illinois Basin.

Geology of the Herrin Coal Relative to Mining

The Herrin Coal has been mined more than any other coal seam in Illinois because of its thickness, its shallow-to-moderate depth throughout extensive areas, and the prevalence of suitable conditions for large-scale mining. The location of all mines operating in the Herrin Coal in Illinois in 1974 is shown in figure 15. These 37 mines, 19 underground mines and 18 strip mines, accounted for 75 percent of the 1973 production of coal in Illinois. The locations of these mines and all other Illinois coal mines are shown on a new map (Hopkins, 1975[38]) prepared on the same scale as the three plates accompanying this report.

Southern and Central Illinois

The Herrin Coal has been mined more extensively in southern Illinois than in any other part of the state. Five of the current underground mines are now operating in the low-sulfur coal area, located in Franklin and Jefferson Counties (fig. 12). In Jackson, Perry, Randolph, and St. Clair Counties, most current production is from strip mines, four of which are mining in both the Herrin Coal and the Harrisburg-Springfield Coal. In central Illinois, large underground mines in Christian, Macoupin, and Montgomery Counties (fig. 15) produce from the Herrin Coal.

In a large area in eastern Fayette County, western Effingham County, eastern Marion County, and western Clay County, the Herrin Coal is less than 42 inches thick. In part of that area it is less than 28 inches thick.

Western Illinois

All of the coal production in western Illinois in recent years has been from strip mines primarily from the Herrin, Harrisburg-Springfield, and Colchester (No. 2) Coals. All active mines except one are now producing from the Herrin and/or the Harrisburg-Springfield Coals, and extensive reserves are shown for these coals in this area (table 8).

The Herrin Coal is now being strip mined in Stark, Peoria, Knox, and Fulton Counties (fig. 15). Large areas of potentially strippable Herrin Coal also are present in southeastern Henry County and southwestern Bureau County (Smith and Berggren, 1963[49]).

In Fulton County, strip mines in the past have mined coal from both the Herrin and Harrisburg-Springfield seams from adjacent strip pits. In this area the two seams are 60 to 75 feet apart. In the counties farther north, however, the Harrisburg-Springfield Coal becomes thinner and only the Herrin Coal has been mined.

Northern Illinois

There is no current mining in the Herrin Coal in northern Illinois (fig. 15). It was formerly mined, principally by underground methods, near Streator in La Salle County and along the Illinois River in both Bureau and La Salle Counties.

The remaining coal reserves in these areas, as shown on plate 1, are small compared to those of other regions of the state. However, in a large part of northern Illinois the coal resources have not yet been adequately assessed because data on which to make an evaluation are scarce.

Eastern Illinois

Three mines are operating at present in the Herrin Coal in eastern Illinois, two near Murdock in eastern Douglas County and one, a small mine, southwest of Danville in Vermilion County (fig. 15). Substantial quantities of additional coal have been mapped in Douglas, Vermilion, and Edgar Counties. For Clark, Coles, and Cumberland Counties, because not enough data are available for mapping the Herrin Coal reserves, no estimate has been made. Farther south, in part of southeastern Illinois, large reserves of Herrin Coal are mapped, but the coal is much deeper there than in other parts of the state and numerous oil pools will seriously limit the minability of the coal in many parts of this region. In southern Cumberland County, eastern Effingham County, and western Jasper County the Herrin Coal has been mapped in large areas, principally from interpretation of geophysical logs of oil and gas wells (Allgaier and Hopkins, 1975[24]). Therefore the Herrin Coal in these Counties has been placed in the Class II category (table 3 and fig. 4).

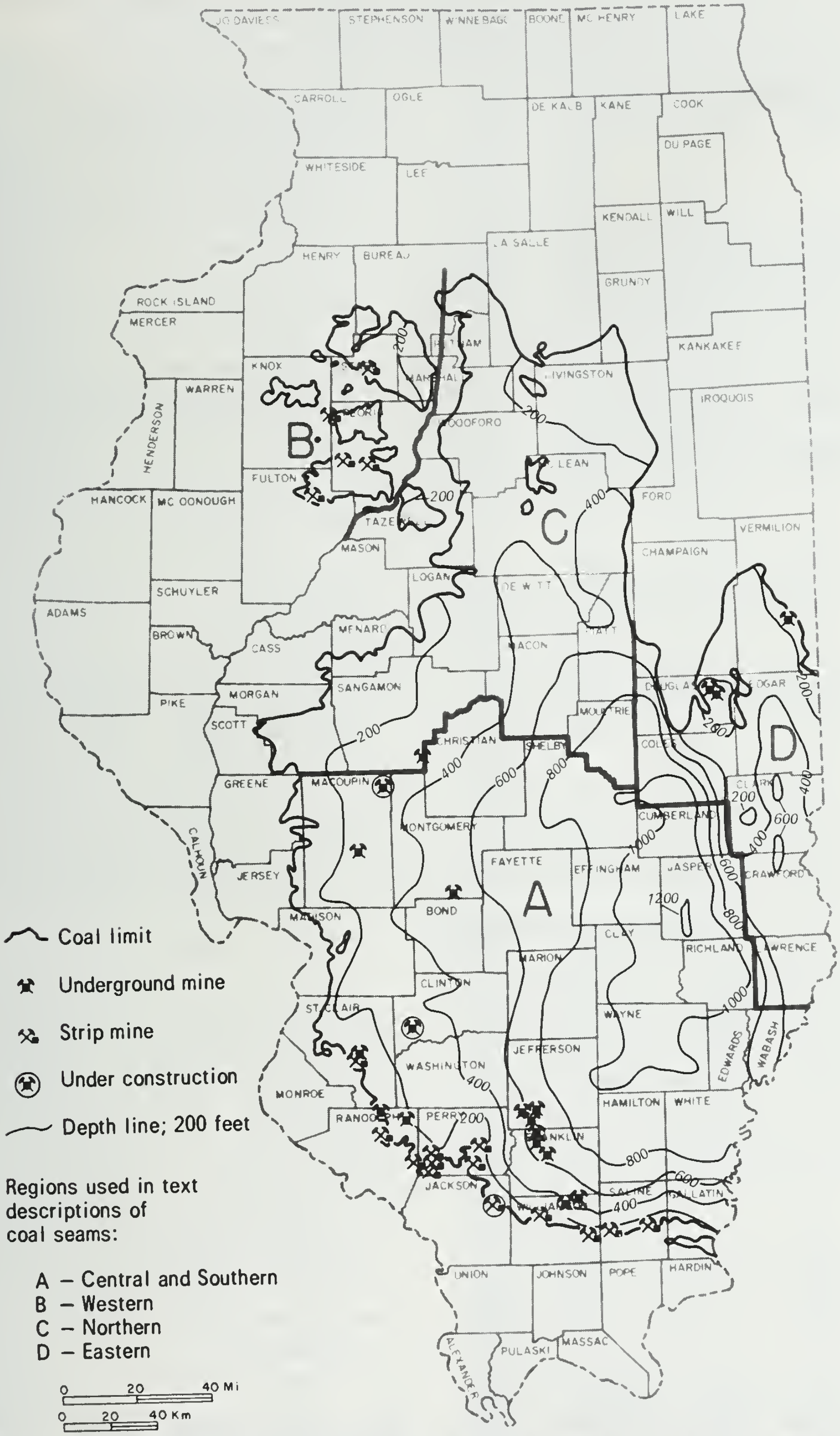


Figure 15. Generalized depth of Herrin Coal. Mines active in the Herrin seam on January 1, 1975, are indicated.

TABLE 8–STRIPPABLE COAL RESERVES IN THE HERRIN (NO. 6) AND HARRISBURG-SPRINGFIELD (NO. 5) COAL MEMBERS BY COUNTY AND RELIABILITY CLASSIFICATION*†

(thousands of tons)

County	Coal seam	Class I reserves at overburden thickness (ft)				Class II reserves at overburden thickness (ft)				Totals I & II	Mined out (sq mi)
		0-50	50-100	100-150	Total	0-50	50-100	100-150	Total		
Bureau	6	24,218	63,058	76,061	163,337	628	29,055	69,095	98,778	262,115	4.91
Cass	6		14,600	5,100	19,700		14,729	21,455	36,184	55,884	
Fulton	6	42,556	126,588	80,142	249,286					249,286	4.93
	5	172,925	389,624	139,837	702,386					702,386	51.19
Gallatin	6	37,104	45,035	32,367	114,506		718	6,681	7,399	121,905	
	5	2,343	29,582	83,924	115,849					115,849	1.64
Greene	6	13,831	23,988	37,540	75,359	9,069	12,555	291	21,915	97,274	
Henry	6	38,919	104,433	49,175	192,527	583	45,107	17,218	62,908	255,435	1.94
Jackson	6	26,969	73,264	49,085	149,318					149,318	9.47
	5	18,585	34,424	46,834	99,843					99,843	1.88
Jersey	6	18,159	23,910	8,452	50,521	807	4,887	1,121	6,815	57,336	
Knox	6	124,723	128,050	4,293	257,066					257,066	11.28
	5	178,543	233,719	55,960	468,222	23,282	77,659	57,346	158,287	626,509	5.50
La Salle	6	14,897	24,480	9,574	48,951	8,732	12,521		21,253	70,204	9.19
Livingston	6	5,829	17,553	1,671	25,053	1,794	2,197		3,991	29,044	3.33
Macoupin	6	36,967	64,264	90,371	191,602	246	16,949	42,013	59,208	250,810	
Madison	6	31,789	165,036	195,200	392,025	1,883	14,942	40,433	57,258	449,283	
Monroe	6	6,726			6,726					6,726	
Morgan	6	4,081	61,759	26,622	92,462	7,466	202,510	183,442	393,418	485,880	
Peoria	6	204,817	404,294	272,710	881,821	5,173	46,873	124,504	176,550	1,058,371	1.85
	5	45,712	173,645	248,778	468,135	28,489	117,689	111,236	257,414	725,549	17.83
Perry	6	136,037	510,782	249,948	896,767					896,767	35.94
	5	33,112	117,156	31,162	181,430		13,182	14,662	27,844	209,274	.58
Randolph	6	51,116	102,241	125,782	279,139					279,139	8.19
	5	41,125	86,795	32,557	160,477	196	6,283	8,934	15,413	175,890	.88
St. Clair	6	101,714	409,091	738,318	1,249,123					1,249,123	36.06
Saline	6	56,125	102,589	125,858	284,572					284,572	6.03
	5	11,782	24,044	57,596	93,422					93,422	10.67
Schuyler	5	79,664	23,204	2,186	105,054	8,340			8,340	113,394	1.03
Scott	6	583	5,537		6,120					6,120	
Stark	6	41,700	158,412	42,949	243,061	2,107	89,329	107,970	199,406	442,467	.25
Tazewell	6	6,097	16,377	35,163	57,637	140	7,034	4,875	12,049	69,686	
	5	1,211	5,851	21,085	28,147			8,928	8,928	37,075	1.35
Warren	5	807			807					807	
Williamson	6	66,461	92,603	131,654	290,718					290,718	33.62
	5	28,294	59,454	112,520	200,268					200,268	7.53
Total	6	1,091,418	2,737,944	2,388,035	6,217,397	38,628	499,406	619,098	1,157,132	7,374,529	166.99
	5	614,103	1,177,498	832,412	2,624,013	60,307	214,813	201,106	476,226	3,100,239	267.07
Totals		1,705,521	3,915,442	3,220,447	8,841,410	98,935	714,219	820,204	1,633,358	10,474,768	267.07

* *Does not include studies now in progress for Springfield (No. 5) Coal in Menard and Sangamon Counties or Herrin (No. 6) Coal in Vermilion and Edgar Counties.*

† *Strippable coals include coals 18 inches or more thick under 150 feet or less of overburden.*

HARRISBURG-SPRINGFIELD (NO. 5) COAL MEMBER

The Harrisburg (No. 5) Coal Member was defined by Shaw and Savage (1912[72]), who named it for exposures and mines near Harrisburg, Saline County. The coal had previously been given the name "Springfield Coal" in the area of Springfield, Sangamon County (Worthen, 1883[82]). Subsequently, the coal was found to be in the same stratigraphic position in both regions, and therefore the form "Harrisburg-Springfield Coal" is used in this report. The seam is correlated with the No. 9 Coal of western Kentucky, the Springfield Coal Member (V) of Indiana, and the Summit Coal of Iowa and Missouri.

In Illinois the Harrisburg-Springfield Coal ranks second only to the Herrin Coal in total mapped reserves. Production from this seam accounted for 16 percent of the 1973 total production. It has been mapped (pl. 2) as being 42 or more inches thick throughout an area of 7,630 square miles, 331 square miles of which has been mined out, leaving 7,299 square miles of in-place reserves estimated at 38 billion tons.

The Harrisburg-Springfield Coal has been extensively mined underground in the Harrisburg region, the Springfield region, near Canton, Peoria, and Pekin, and in a large new mine near Keensburg in Wabash County. After World War II, strip mining in this seam increased, and many of the underground mines were closed. Along the outcrop in Gallatin, Saline, Williamson, Perry, and Randolph Counties, and in Fulton County, this seam has been extensively strip mined. In some areas it was, and still is in a few places, the principal seam mined, while in other areas it is strip mined along with the overlying Herrin Coal.

Thickness of the Coal

The Harrisburg-Springfield Coal averages about 1 foot thinner than the Herrin Coal. As determined in this study, its weighted average thickness in Illinois is 4.55 feet, compared to 5.52 feet for the Herrin Coal. The generalized thickness of the Harrisburg-Springfield Coal is shown in figure 16. It shows that the thickest coal is in southeastern Illinois adjacent to the prominent sandstone-filled channel mapped by Hopkins (1968[37]). The relation between coal thickness and proximity to the channel shown in figure 16 and plate 2 is similar to that shown for the Herrin Coal in figure 14 and plate 1. A similar relation is apparent between the low-sulfur areas of the two coals and the proximity of the coals to channels that existed during coal deposition, as shown in figures 12 and 13.

Other large areas of Harrisburg-Springfield Coal mapped in this study are located in the Springfield region and in the vicinity of Peoria and Canton in western Illinois. In both of these regions the coal is at least 5 feet thick in considerable areas. In the vicinity of Springfield and Peoria the coal formerly was mined rather widely in underground mines, whereas around Canton it has been extensively strip mined. In other parts of the state the Harrisburg-Springfield is either thin (less than 28 inches thick) or there is insufficient information available to warrant mapping the coal reserves.

Depth of the Coal

The depth of the Harrisburg-Springfield Coal is shown in figure 17. The Harrisburg-Springfield ranges from 10 to 130 feet below the Herrin seam (fig. 20). Like the overlying Herrin Coal, it is being strip mined near the margins of the Illinois Basin. Only 4.5 percent of the area of original Harrisburg-Springfield reserves mapped in this study has been mined out. It seems probable that the greater general thickness of the overlying Herrin Coal rather than the slightly greater depth of the Harrisburg-Springfield Coal has been largely responsible for the less extensive development of the lower coal.

Geology of the Harrisburg-Springfield Coal Relative to Mining

The Harrisburg-Springfield Coal has been extensively mined near Harrisburg, along its outcrop in southern Illinois, near Springfield, and near Peoria and Canton in western Illinois.

The locations of 16 mines operating in this coal in 1974 are shown in figure 17, 10 of them strip mines and 6 of them underground mines. In 1973 these mines accounted for 16 percent of the state's total coal production.

Southern and Central Illinois

In southern Illinois the Harrisburg-Springfield Coal is being strip mined at several places along its outcrop in Randolph, Perry, and Williamson Counties. Near Harrisburg, Saline County, it has been strip mined along its outcrop and was formerly mined underground much more extensively than it has been in recent years, although two underground mines still are operating there (fig. 17). As can be seen in figure 13, much of the coal formerly mined near Harrisburg had a lower sulfur content than that mined elsewhere in the region.

Hopkins (1968[37]) mapped reserves totaling 11.8 billion tons for coal 42 or more inches thick in the Harrisburg-Springfield (No. 5) Coal in southeastern Illinois. This included substantial quantities of low-sulfur coal in a belt along the prominent sandstone channel that extends northward from the vicinity of Harrisburg to Wabash County (figs. 13, 16, and pl. 1). Much of the coal along this belt is thicker than the coal elsewhere in the region. One new mine is now operating in this low-sulfur coal in Wabash County, and another is under construction in Hamilton County.

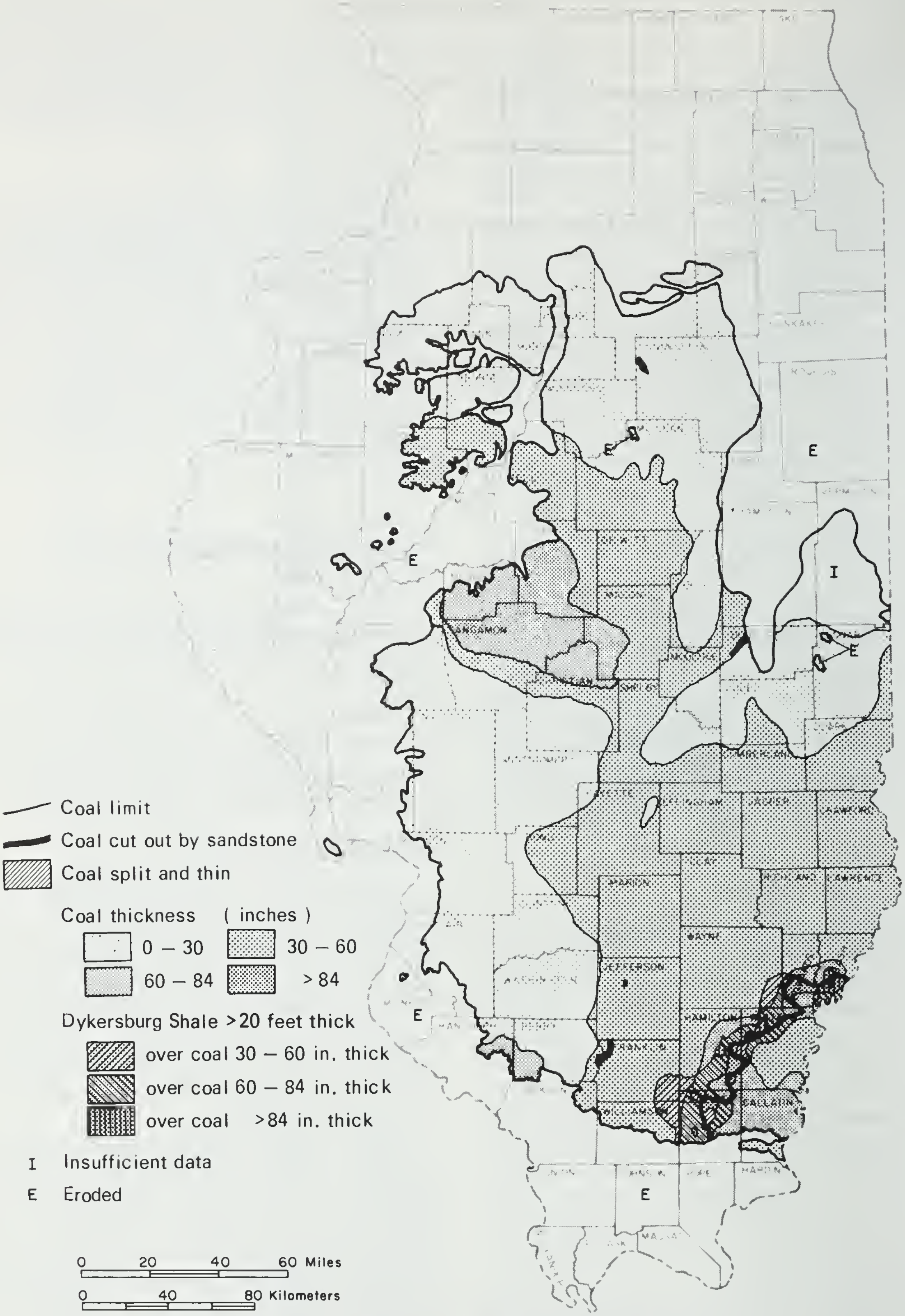


Figure 16. Generalized thickness of Harrisburg-Springfield Coal.

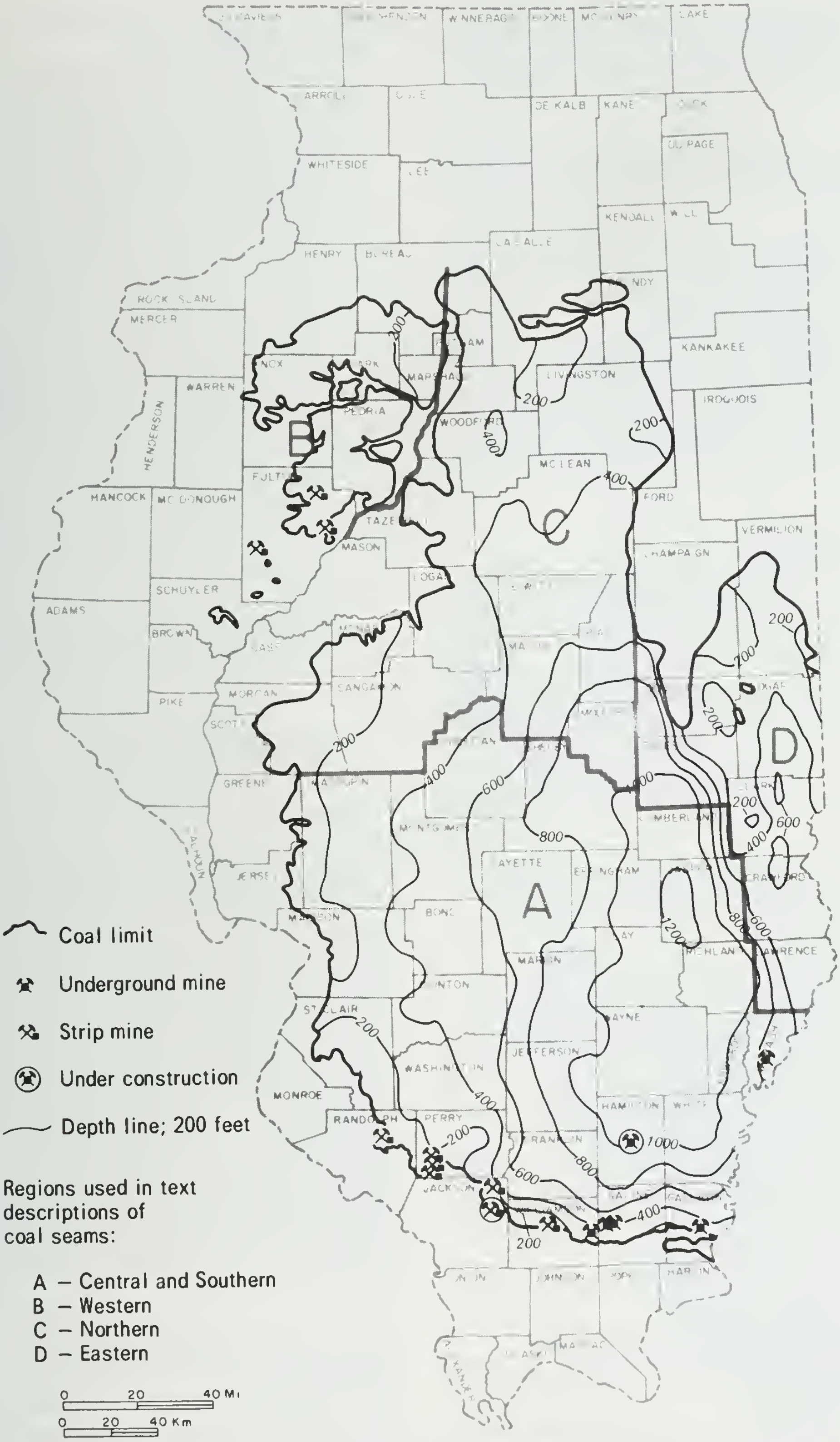


Figure 17. Generalized depth of the Harrisburg-Springfield Coal. Mines active in the Harrisburg-Springfield seam on January 1, 1975, are located.

In central Illinois some of the Harrisburg-Springfield Coal that is mapped on plate 2 is less than 42 inches thick. However, for much of this region only scattered information is available from coal test drilling. In the central Illinois area where reserves have been mapped, the estimate is based mainly on interpretation of coal thickness from electric logs of oil test holes, following the procedures described by Hopkins (1968[37]).

Electric logs also have been used to interpret coal thickness and to estimate reserves in large parts of Marion County and northwestern Jefferson County. Other counties in this region were not mapped for the present study because no information is available from coal test holes. There are, however, numerous oil well logs from which a systematic study could be made of the coal reserves, as Allgaier and Hopkins (1975[24]) did for the Herrin Coal in southeastern Illinois.

Northern and Western Illinois

The Harrisburg-Springfield Coal averages 4 to 5 feet or more thick in a large area that extends from the Decatur-Springfield region northward and westward to the Peoria-Canton region. This area of relatively thick coal probably was once much more extensive, but in large areas between the Sangamon Valley north of Springfield and the Illinois Valley near Peoria (pl. 2) the coal has been eroded.

The Harrisburg-Springfield Coal was formerly mined at numerous places in western Illinois, in spite of which the remaining reserves are very large. In fact, more coal remains than has been mined. Within this region the reserves (pl. 2) are potentially great enough to support several facilities for coal conversion.

Eastern Illinois

In Edgar, Clark, Crawford, and Lawrence Counties, the reserves (pl. 2) border areas in Indiana where the coal is not as deep and therefore has been more extensively mined. Information regarding the Illinois coal has been obtained from general knowledge of Indiana mines and from limited mining and exploratory drilling in Illinois. For the remaining areas of eastern Illinois, however, reserves of the Harrisburg-Springfield seam have not been mapped because of a paucity of information.

GEOLOGICAL FACTORS AFFECTING MINABILITY OF THE COALS

A total area of 1,258 square miles has been mined to date for the Herrin and Harrisburg-Springfield Coals, 7.1 percent of the area of original reserves mapped in this study (table 5). Substantial information on mining conditions that has been garnered from past mining provides the best guide to the mining conditions that are likely to be encountered in the future.

For more than 60 years the Geological Survey has been engaged in studying the coals and their associated roof and floor strata as mining and exploratory drilling in Illinois has progressed. Much has been learned from these investigations about geological features that affect the minability of the coal seams, and the Geological Survey has published regional reports covering much of the Illinois coal field area that show structure contours on the coal, location of faults, major sandstone channels, and other geological features that are important to the planning of mines.

The Illinois Geological Survey is currently engaged in a study, partially funded by the U.S. Bureau of Mines, of the geologic characteristics of the roof of the Herrin Coal in the major areas of underground mining. The investigation is concerned with determining how the geology of the strata above the coal might be related to roof failures. Structural features and the stratigraphy of selected areas of the roof in representative mines are being mapped in detail, and regional maps showing the characteristics of the strata several feet above the coal are being prepared. The results of the study should be valuable for the planning of future mines.

Areas Depleted by Past Mining

Much of the mining in Illinois in the past was concentrated in the areas of thickest coal near the outcrop, along major railroad lines, or in the areas in which the coal is relatively low in sulfur (figs. 12 and 13). The location of all mined-out coal areas in Illinois and all mines operating on January 1, 1975, are shown on a map newly issued by the Geological Survey (Hopkins, 1975[38]). More detailed information on mined-out areas is shown on maps available from the Illinois Geological Survey (fig. 18).

The Geological Survey has for many years maintained files of geological information regarding individual mines. Observations of mining conditions relating to geology have been collected by Survey geologists and are available for public inspection. Some of the observations of mining conditions were made in the early part of this century when many more individual mines operated in Illinois than at present, and they contain information valuable for the planning of new mines.

Areas Closely Drilled for Oil or Gas

Oil and gas fields in which holes are closely spaced were excluded from the estimates of coal resources in this study. In much of southeastern Illinois a substantial portion of the original in-place coal resources lie above oil pools and are not at present considered recoverable. In these places oil wells producing from depths of less than 4,000 feet are

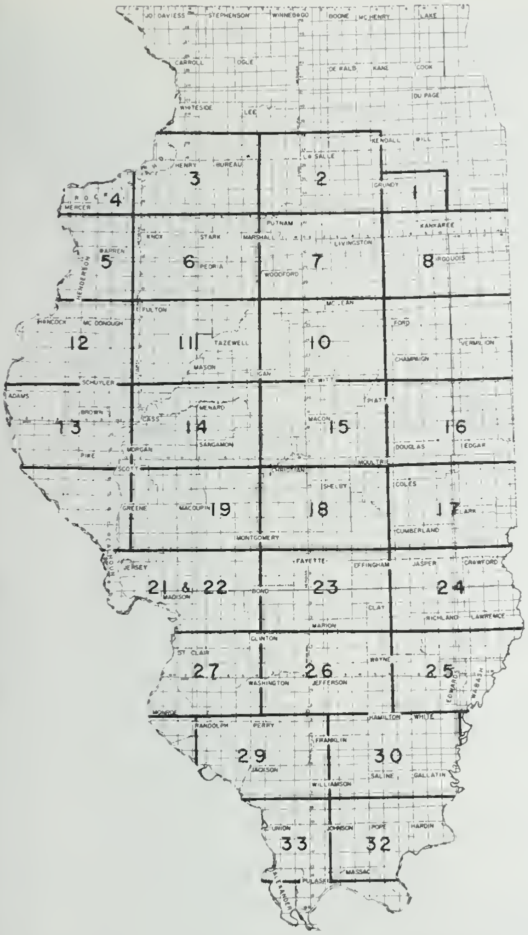


Figure 18. Index to maps of areas where coal has been mined out. Maps are available from the Illinois State Geological Survey, Urbana.

normally spaced to allow 10 acres per well (660 feet apart) where production is from sandstone and 20 acres per well where the production is from limestone. For wells producing from depths between 4,000 and 6,000 feet, the spacing is 40 acres per well. Since Federal mining law prohibits mining within an area 300 feet in diameter surrounding each well unless special precautions are taken, the coal in these areas cannot be effectively mined unless the wells are adequately plugged and permission to mine obtained from the authorities. New methods of plugging abandoned wells are being developed (Rennick et al., 1972[71]) that would permit mining without leaving the large barrier pillar around each well.

Approximately 100,000 test holes have been drilled for oil or gas within the coal-bearing areas of Illinois, many of which will affect the recoverability of the state's coal reserves. Fortunately, most oil test holes in Illinois are quite adequately recorded, and maps that show the number and distribution of wells are available for mine planners to consult. Figure 19 is the index to a series of maps (scale, 2 inches equal 1 mile) available from the Illinois Geological Survey that show the location of holes drilled for oil or gas, as well as many other kinds of test holes. Logs and other pertinent records, including information on well plugging, for essentially all of these test holes also are available for examination at the Geological Survey.

Areas Affected by Sandstone Channels and Split Coal

The presence of sandstone channels, described earlier, will influence the siting of new mines in some areas because where the channels have cut out the coal the lateral extent of the mines may be limited. Poor mine roof conditions and, in some instances, shale or sandstone partings in the coal seam occur in areas near the channels. Channel sandstone deposits in the roof strata must also be considered, even when they are at some distance above the coal, because, in addition to their direct effect on the stability of the roof strata, they may contain large amounts of water that can adversely affect roof shales. The water may also enter the mine and interfere with mining operations.

Future exploration for coal and actual mining activities undoubtedly will disclose additional channels. However, the major channels and their trends, especially those in the Herrin Coal, are now believed to be fairly well known, except in areas of east-central Illinois where there are obvious gaps in the mapped continuity of the channels (pls. 1 and 2). Sandstone was reported by Potter and Simon (1961[70], pl. 1) in many mines, either in the roof or partially or totally replacing the Herrin Coal in west-central Illinois.

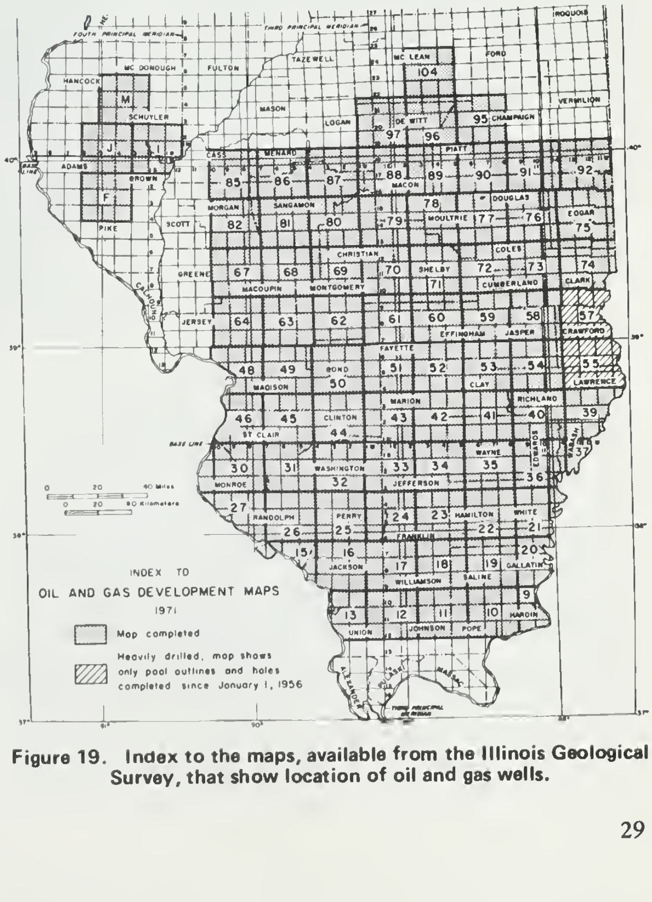

FOURTH PRINCIPAL MERIDIAN
THIRD PRINCIPAL MERIDIAN
BASE LINE
INDEX TO
OIL AND GAS DEVELOPMENT MAPS
1971
Map completed
Heavily drilled, map shows only pool outlines and holes completed since January 1, 1956
0 20 40 Miles
0 20 80 Kilometers

Figure 19. Index to the maps, available from the Illinois Geological Survey, that show location of oil and gas wells.

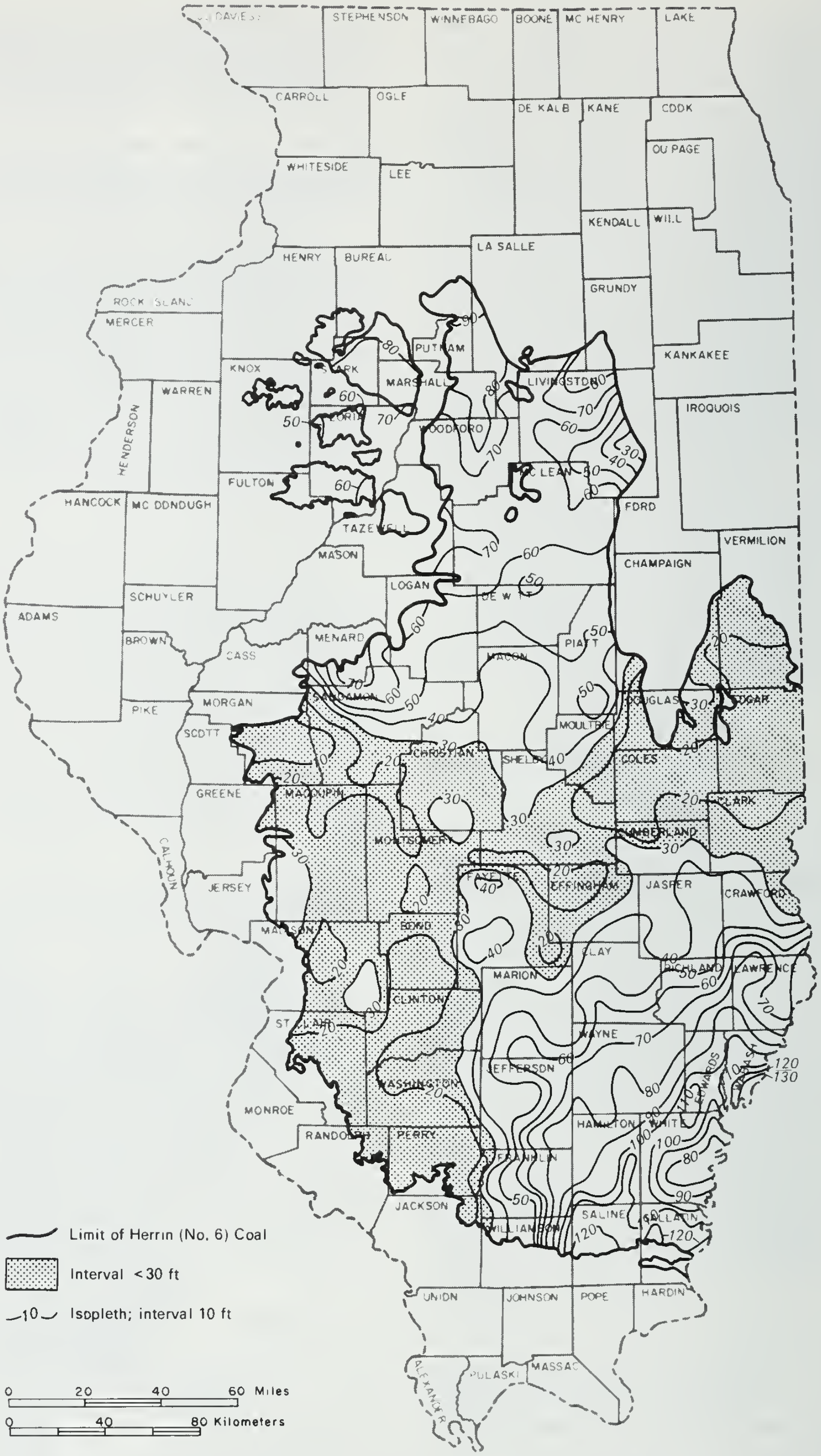


Figure 20. Generalized thickness of the interval between the Herrin and Harrisburg-Springfield Coals.

Roof and Floor Conditions

Some mine roof problems occur in all mines and many appear to be related to variations in the lithologic sequence and changes in structural properties of the roof strata into which the roof bolts are set. In spite of many local exceptions, the strata composing the roof and floor of the Herrin and Harrisburg–Springfield Coals can be described in general because of the widespread uniformity of many of the lithologic units.

Both seams are characteristically overlain by black shale, generally less than 3 feet thick, which is in turn overlain by widespread marine limestone members. Although somewhat similar in lithology, the limestone members differ characteristically in physical appearance and in fossil content. In certain areas, however, the marine limestone (especially above the Herrin Coal) is somewhat lenticular, a condition that causes roof problems where the limestone is very thin or absent. In many of the regions where the seams have been or are now being mined, the sequence of strata forming the roof is relatively uniform and provides average-to-good roof conditions.

The floor of most mines operating in the two coals commonly consists of gray claystone that causes few problems, except when it becomes wet during mining. In a few places, however, a local change in the moisture content or mineralogy of the strata below the coal may increase the tendency of the clay to "squeeze" from beneath coal pillars. When that happens, the argillaceous materials flow plastically into the floor strata of the mined-out rooms and entries, causing the floors to heave and impede mining (White, 1956[77]; report in preparation[78]).

The Illinois Geological Survey is investigating ways in which areas of unstable underclay can be identified during exploratory drilling. Mines could then be designed to cope with or avoid the problems caused by the underclays.

Interval between Herrin and Harrisburg–Springfield Coals

A map showing the thickness of the interval between the Herrin and Harrisburg–Springfield Coals (fig. 20) was prepared by using the computerized geological mapping program described in Appendix 2. The interval between the two coals ranges from 10 feet or less to more than 130 feet. Where they are less than 30 feet apart, as indicated by the stippled area on figure 20, only one of the two seams, commonly the Herrin, is likely to be more than 42 inches thick. Even in areas where both seams are thick enough for mining and are less than 30 feet apart, it is questionable whether both seams can be mined underground. However, both seams may be strip mined, and strip mines are now operating in both coals in several mines in southwestern Illinois.

In southern and southeastern Illinois where the interval separating the Herrin from the Harrisburg–Springfield Coal is greater than in the southwest, each coal exceeds 4 feet thick in many localities and they could both be mined if it proved economically feasible. However, up to the present, no underground mining of both seams has been undertaken.

Clastic Dikes and White-Top

In both the Herrin and Harrisburg–Springfield Coals, irregular claystone-filled cracks called clastic dikes have been encountered in mines (Damberger, 1970[64]). They vary in width from a few inches to a few feet and may extend vertically throughout the thickness of the coal. Many extend into the roof strata but not into the floor. The dikes have been observed in the Harrisburg–Springfield Coal, principally in the Springfield and Peoria regions, in both strip and underground mines. In the Herrin Coal they are particularly plentiful in the northwestern portion of the Illinois coal field and less numerous in west-central Illinois. When encountered in underground mines, dikes often cause problems with roof stability. In strip mines they cause only minor problems. They contribute to the ash content of the coal as mined.

In northwestern Illinois the Herrin Coal is also disturbed by white-top—in which the top layers of coal are replaced and infiltrated by light gray, often silty claystone. White-top is always associated with clastic dikes. Herrin (No. 6) Coal affected by white-top is widely mined in strip mines of northwestern Illinois, but the resultant undulating surface of the coal seam and the presence in varying thicknesses of the claystone layer and associated clastic dikes in the coal seam are hard on the equipment. It is also difficult to separate the finely dispersed clay from the coal in preparation plants.

The intensity of occurrence of clastic dikes and white-top in the two coals and their distribution in the state are shown in figure 21.

CONCLUSIONS

Reserves of approximately 97 billion tons of coal 42 or more inches thick remain in the two most productive coal seams of Illinois, the Herrin (No. 6) and the Harrisburg–Springfield (No. 5) Coal Members. This estimate does not include the coal from these two seams that cannot be mined by present methods under existing laws because it overlies oil pools. Also excluded from the estimate are areas where the coal has been mined out or is missing because geologic features such as sandstone-filled channels have disrupted the coal. Areas in which the coal is thin or for which there is a dearth of information were not included, nor were areas

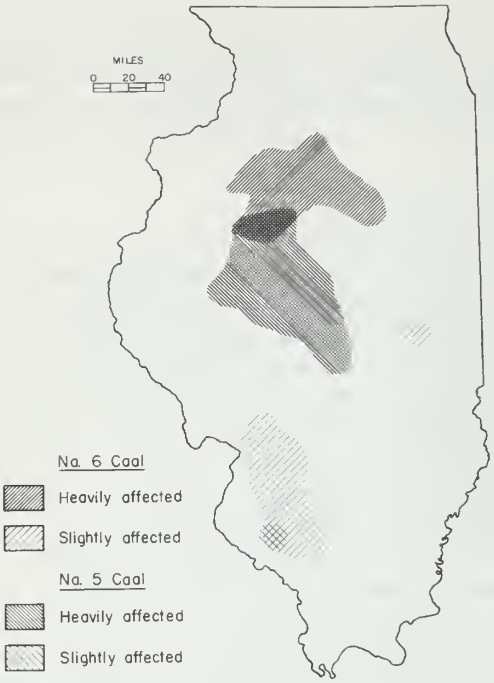


Figure 21. Areas in Illinois affected by claystone dikes and white-top (from Damberger, 1970[64]).

adjacent to the channels where the coal is known to be split by partings of shale or sandstone.

As the large-scale underground mines needed to supply a coal conversion industry will be developed in the thicker coals, 42 inches was the minimum thickness selected for reserves estimates. Only the Herrin and Harrisburg-Springfield Coals were mapped for the study because they are the most extensive and thickest of the Illinois coals, but additional reserves are available in thinner and less extensive coal seams of the state. However, the reserves mapped in the Herrin and Harrisburg-Springfield Coals are clearly sufficient to supply coal for numerous conversion plants that will be located in Illinois.

The data base of coal and water resources in Illinois that has been compiled for this report can now be further interpreted and integrated with other data by systems analysis. Many of the variables that must be considered before selection of sites for coal conversion plants, or for other facilities that require large quantities of coal and water, can thus be comprehensively evaluated to determine the best possible locations for such installations.

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Part 2. Water Resources

John B. Stall

INTRODUCTION

Illinois has abundant water resources. Annual rainfall ranges from 32 inches in northern Illinois to 46 inches in southern Illinois. Annual runoff to streams ranges from 8 inches in the northern part of the state to 15 inches in the southern part. In addition to the water within the state, Illinois is almost surrounded by water—the Mississippi River on the west, the Ohio and Wabash Rivers on the south and east, and Lake Michigan on the northeast.

Illinois also has a large supply of ground water. Most municipal water supplies in Illinois are obtained from ground-water reservoirs. Water-bearing formations with high yields include limestone and sandstone strata in the bedrock and glacial deposits of sand and gravel.

Illinois water resources are as large today as they were when the area was a wilderness. As far as modern science can determine, they will continue to be undiminished, for they are constantly renewed by a great inflow of atmospheric moisture, or water vapor, that passes over Illinois at an average rate of 2,000 billion gallons per day. Rainfall from this moisture averages 99 billion gallons per day (bgd). The total annual runoff to streams in Illinois is 23 bgd. When the dependable flows of the Mississippi and Ohio Rivers are added, a total supply of 53 bgd is available. This is an immense amount of water—more than 3 times the amount now used in Illinois and a sixth of the water used for all purposes in the entire United States.

The quantities of water needed for coal conversion were considered in the main Introduction to this report (table 2). This section deals with locations in Illinois at which the water resource could be developed to produce 6 to 72 mgd. The sources of water considered are ground water, rivers, man-made reservoirs, and wastewater treatment plants. Each is considered separately, although more than one source may be tapped for a single coal conversion plant.

Acknowledgments

The compilation of results on water resources has been prepared in the Hydrology Section of the Water Survey. The work was under the general supervision of Dr. William C. Ackermann, Chief. The material on ground-water availability was developed by Richard J. Schicht, Thomas A. Prickett, and Adrian P. Visocky. Information on the water available from potential reservoirs was collected by Nani G. Bhowmik and Julius H. Dawes, with the help of Wyndham J. Roberts. The water supply available from major rivers was determined by Krishan P. Singh. Data on the cost of reservoir construction were compiled by Dr. Bhowmik. Illustrations for Part 2 were prepared by John W. Brother, Jr.

OCCURRENCE OF GROUND WATER IN ILLINOIS

Ground water in Illinois is affected in many ways by the geology of the state. Permeable rock formations such as sandstone, limestone, sand, and gravel serve as aquifers in which water is stored and ultimately supplied to wells. Impermeable beds, such as shale and clay, act as barriers to ground-water movement and maintain differences in pressure and water quality between aquifers. In some areas, creviced limestone or dolomite formations at land surface make the ground water susceptible to pollution. The configuration and deformation of the bedrock commonly influence ground-water movement.

Ground water in Illinois is commonly drawn from unconsolidated deposits of sand and gravel in the glacial drift or in river valleys, or from bedrock formations of limestone or sandstone. Figure 22 shows the principal water-yielding rocks or aquifers of Illinois.

The most favorable ground-water conditions are found in the northern third of the state, where dependable sandstone and limestone aquifers occur in the bedrock and extensive sand and gravel aquifers are found in the glacial drift. In most of Illinois, the only aquifers of high potential yield are sand and gravel deposits of the Mississippi, Illinois, Wabash, Ohio, Kaskaskia, Embarras, and buried Mahomet River Valleys.

Ground Water from Sand and Gravel Aquifers

Most unconsolidated, or sand and gravel, aquifers of Illinois were deposited by meltwater from glaciers. The sand and gravel were deposited mainly in valleys leading away from the melting ice or in outwash plains at the front of the ice.

The distribution of sand and gravel aquifers and their estimated yields to individual wells are shown in figure 23. General areas are indicated where conditions are especially favorable for drilling wells with large yields. However, test drilling is required to locate satisfactory well sites, because conditions vary from place to place.

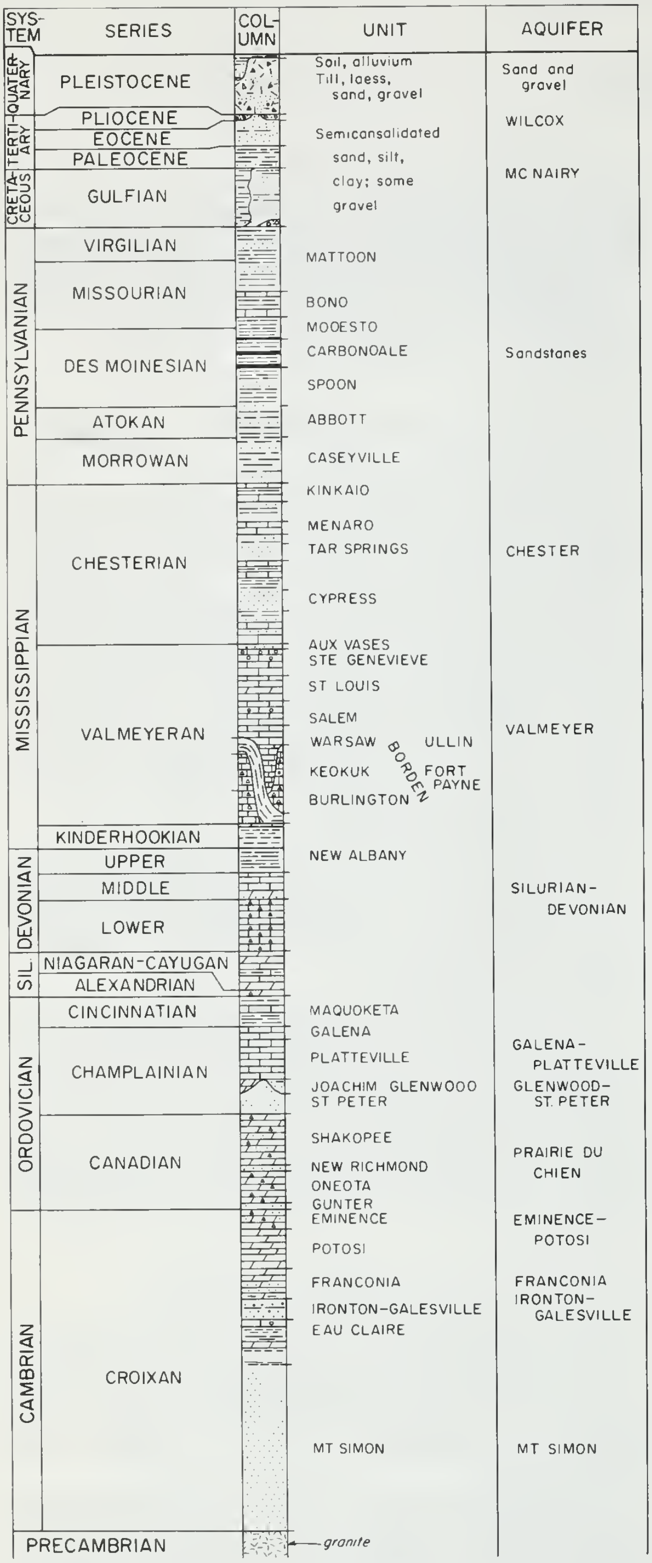

Figure 22. Geologic column of Illinois. The position of the major aquifers is indicated.

Most of the areas in which conditions are favorable for drilling sand and gravel wells that will yield more than 500 gpm contain water-yielding sand and gravel lying within major valley systems. These systems include the Mississippi, Illinois, Ohio, and Wabash River Valleys, the buried Mahomet Valley in east-central Illinois, and several buried and surface valley systems in the northern third of the state. Large quantities of water are available from relatively shallow wells, many drilled to depths of less than 300 feet.

Ground Water from Bedrock Aquifers

In the northern third of the state, large quantities of ground water for industrial and municipal use come from wells in the deep sandstone aquifers of Cambrian and Ordovician ages and from the shallow dolomite aquifers of Silurian and Ordovician ages (fig. 24). The Ironton–Galesville Sandstone is the main bedrock aquifer because of its consistently high yield. Part of the yield of many high-capacity, deep sandstone wells comes from the Glenwood–St. Peter and Mt. Simon Sandstones. Many deep sandstone wells have yields exceeding 700 gpm and have been prolific sources of water for nearly 100 years. Deep sandstone wells average about 1,300 feet deep, and many recent wells are 16 to 20 inches in diameter. Some deep wells in the northern part of the state are open to and draw water from several different aquifers, including the Galena–Platteville Dolomite, Glenwood–St. Peter Sandstone, Ironton–Galesville Sandstone, and Mt. Simon Sandstone. These water-yielding formations are sometimes grouped as the Cambrian–Ordovician aquifer.

Shallow dolomite aquifers of Silurian age and the Galena–Platteville Dolomite of Ordovician age are the main sources of ground water for many moderate-to-large public and industrial supplies in the northern third of Illinois. The average depth of shallow dolomite wells is about 140 feet, and most wells of recent design are 12 to 16 inches in diameter.

In the southern two-thirds of Illinois, thin sandstone and limestone beds of Pennsylvanian age and sandstone and limestone formations of Mississippian age yield small quantities of ground water. Although wells in these rocks commonly yield less than 25 gpm, they are the only source of water for several thousand farms and homes, several hundred small municipalities, and numerous industries. Deeper rocks in this area contain water that is too highly mineralized for most purposes. The Pennsylvanian and Mississippian rocks are also an important source of water for water-flooding operations in oil fields. The average depth of wells in Pennsylvanian rocks is 170 feet and the average in Mississippian rocks is 250 feet. Many wells are 6 to 12 inches in diameter.

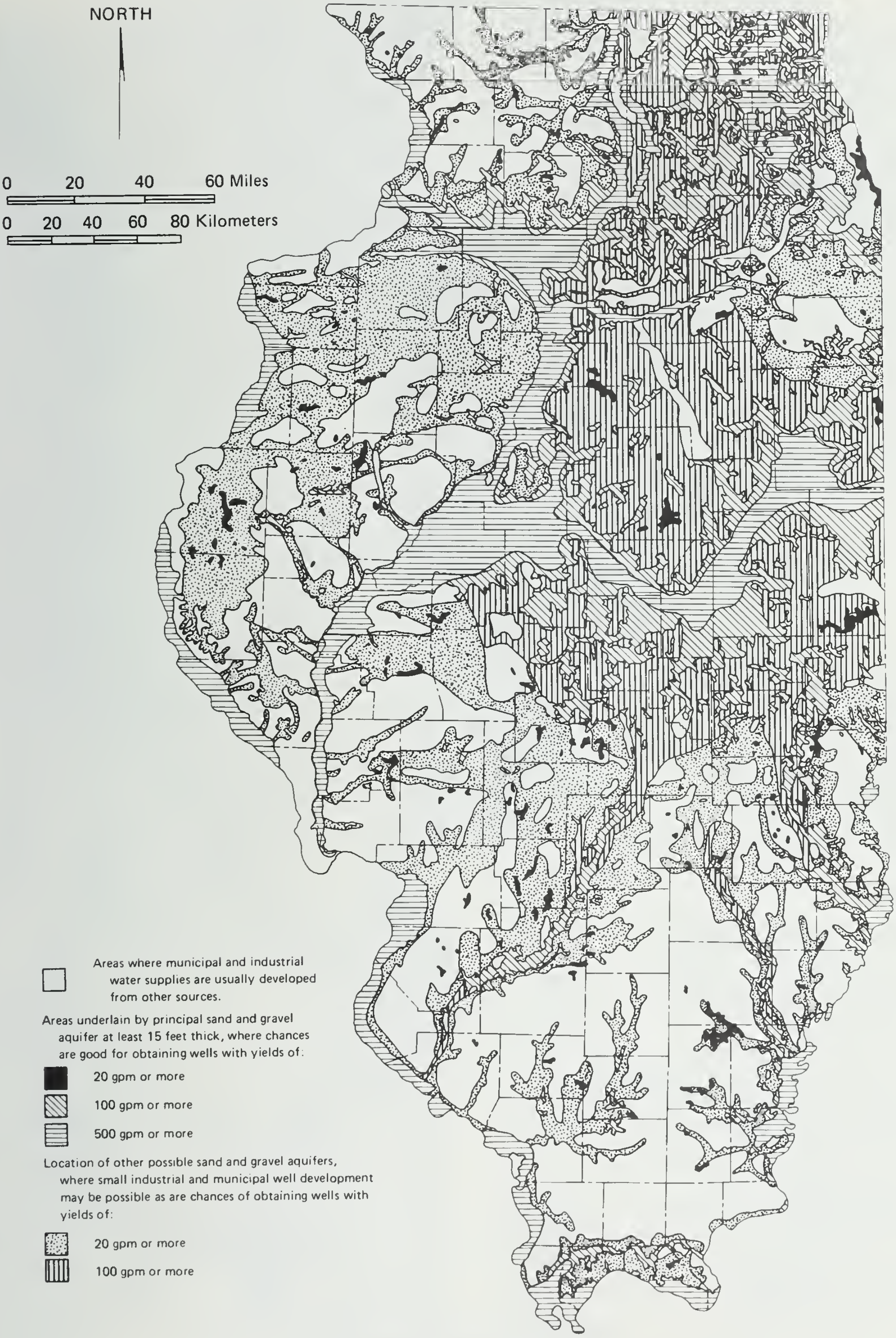
NORTH
0 20 40 60 Miles
0 20 40 60 80 Kilometers
☐ Areas where municipal and industrial water supplies are usually developed from other sources.
Areas underlain by principal sand and gravel aquifer at least 15 feet thick, where chances are good for obtaining wells with yields of:
■ 20 gpm or more
▧ 100 gpm or more
▤ 500 gpm or more
Location of other possible sand and gravel aquifers, where small industrial and municipal well development may be possible as are chances of obtaining wells with yields of:
▒ 20 gpm or more
▥ 100 gpm or more

Figure 23. Yields of sand and gravel aquifers.

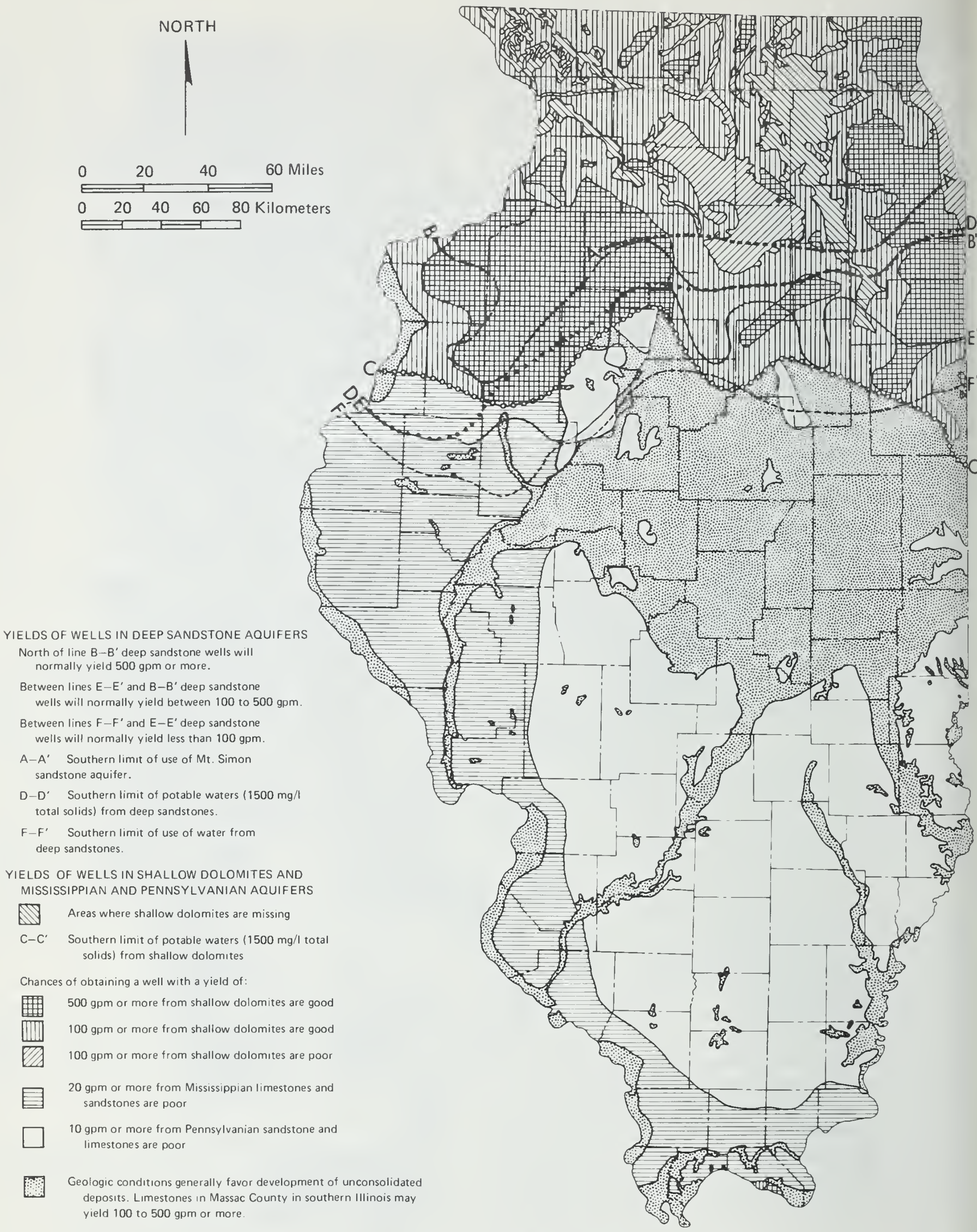
NORTH
0 20 40 60 Miles
0 20 40 60 80 Kilometers
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
YIELDS OF WELLS IN DEEP SANDSTONE AQUIFERS
North of line B–B' deep sandstone wells will normally yield 500 gpm or more.
Between lines E–E' and B–B' deep sandstone wells will normally yield between 100 to 500 gpm.
Between lines F–F' and E–E' deep sandstone wells will normally yield less than 100 gpm.
A–A' Southern limit of use of Mt. Simon sandstone aquifer.
D–D' Southern limit of potable waters (1500 mg/l total solids) from deep sandstones.
F–F' Southern limit of use of water from deep sandstones.
YIELDS OF WELLS IN SHALLOW DOLOMITES AND MISSISSIPPIAN AND PENNSYLVANIAN AQUIFERS
▧ Areas where shallow dolomites are missing
C–C' Southern limit of potable waters (1500 mg/l total solids) from shallow dolomites
Chances of obtaining a well with a yield of:
▦ 500 gpm or more from shallow dolomites are good
▥ 100 gpm or more from shallow dolomites are good
▨ 100 gpm or more from shallow dolomites are poor
▤ 20 gpm or more from Mississippian limestones and sandstones are poor
☐ 10 gpm or more from Pennsylvanian sandstone and limestones are poor
▒ Geologic conditions generally favor development of unconsolidated deposits. Limestones in Massac County in southern Illinois may yield 100 to 500 gpm or more.

Figure 24. Yields of bedrock aquifers.

AVAILABILITY OF GROUND WATER FOR COAL CONVERSION

The quantity of water needed for coal conversion plants was estimated in table 2 as being between 6 and 72 mgd. In terms of ground-water development, that is a vast supply. Therefore, only locations where ground-water conditions are especially favorable can be considered as possible sites. In Illinois favorable conditions exist in areas where yields of wells are high (in excess of 500 gpm), where the aquifers are extensive and highly permeable, and where either the natural rate of recharge is high or water can be induced (by pumping of near-by wells) to flow from the streams into the ground-water reservoir, a process called induced infiltration.

Selected Areas for Ground-Water Development

Sand and gravel aquifers that meet the desired conditions are found in the major bedrock valleys of Illinois or their buried counterparts. Such deposits are shown in figure 23 as areas in which chances of obtaining wells with yields of 500 gpm or more are good.

Bedrock aquifers are most likely to be present in deep sandstones and shallow dolomites in the northern third of the state. Figure 24 shows the areas wherein individual bedrock well yields are estimated to be more than 500 gpm.

Conditions are not considered favorable for extensive ground-water development in areas where estimated well yields are less than 500 gpm. Available geohydrologic data from such areas strongly suggest that an unreasonably large number of wells and well fields, placed with unusually large spacings, would be necessary to produce the large supplies of water needed for coal conversion plants.

Some of the potential areas for extensive development of ground water are already supporting concentrated pumping centers that would be in direct competition with new pumpage from coal conversion plants. For this reason northeastern Illinois and the Peoria–Pekin area are excluded from consideration, and in the East St. Louis area only ground water available in excess of present pumpage is considered.

In figure 25, 17 areas of Illinois are shown where water well systems can be developed that are capable of yielding an estimated 14 to 72 mgd. In each region a system of wells could be drilled, connected, and pumped together to provide the water supply needed. A digital computer model or mathematical model, based on available hydrologic and geologic data, was constructed for each of the areas. The model was used to determine the spacing of wells so that safe pumping levels could be maintained in a continuous pumping situation. Table 9 identifies the 17 areas by county, by the supply available in mgd, and by the source of the ground water.

Hydrogeologic Data

Table 10 gives the locations of the 17 selected areas noted in table 9 and the major hydrogeologic properties of each area. The properties summarized in the table are relevant to the availability of ground water. In general, the higher the rate, permeability, and thickness, the more favorable the conditions for pumping large quantities of ground water. The river infiltration rates are a measure of the quantities of water that can be drawn from the river into the aquifer by pumping wells to supplement natural recharge and thus sustain the well field. The estimated river infiltration rates in table 10 are based on a correlation study of known rates from hydrogeologically similar areas. The infiltration rates are expressed in gallons per day per acre of riverbed per foot of head difference between head in the river and that in the aquifer (gpd/acre/ft). The permeability of the aquifer expressed in gallons per day per square foot of aquifer (gpd/sq ft) is one measure of the rate of flow that the aquifer might transmit to a well. The permeability values are based on averages computed from pumping tests already made in each of the areas under study.

TABLE 9—WATER SUPPLIES AVAILABLE FROM GROUND WATER

(Locations are shown in figure 25)

Area no. on fig. 25	County	Amount (mgd)	Source
1	Carroll	14	Gravel near Mississippi River
2	Henderson and Mercer	14	Gravel near Mississippi River
3	Hancock	72	Gravel near Mississippi River
4	Pike	72	Gravel near Mississippi River
5	Monroe and Randolph	72	Gravel near Mississippi River
6	Jackson and Union	72	Gravel near Mississippi River
7	Alexander and Pulaski	72	Gravel near Mississippi River
8	Massac	28	Gravel near Ohio River
9	Gallatin and White	72	Gravel near Wabash River
10	Lawrence	28	Gravel near Wabash River
11	Greene, Jersey, and Scott	72	Gravel near Illinois River
12	Mason	72	Gravel near Illinois River in Havana Lowlands (Walker et al., 1965)
13	Bureau	72	Shallow glacial gravel
14	Ogle	72	Deep sandstone in the bedrock
15	De Witt and Piatt	72	Buried Mahomet Valley (Visocky and Schicht, 1969)
16	Ford	72	Buried Mahomet Valley (Visocky and Schicht, 1969)
17	Madison	28	East St. Louis area (Schicht, 1965)

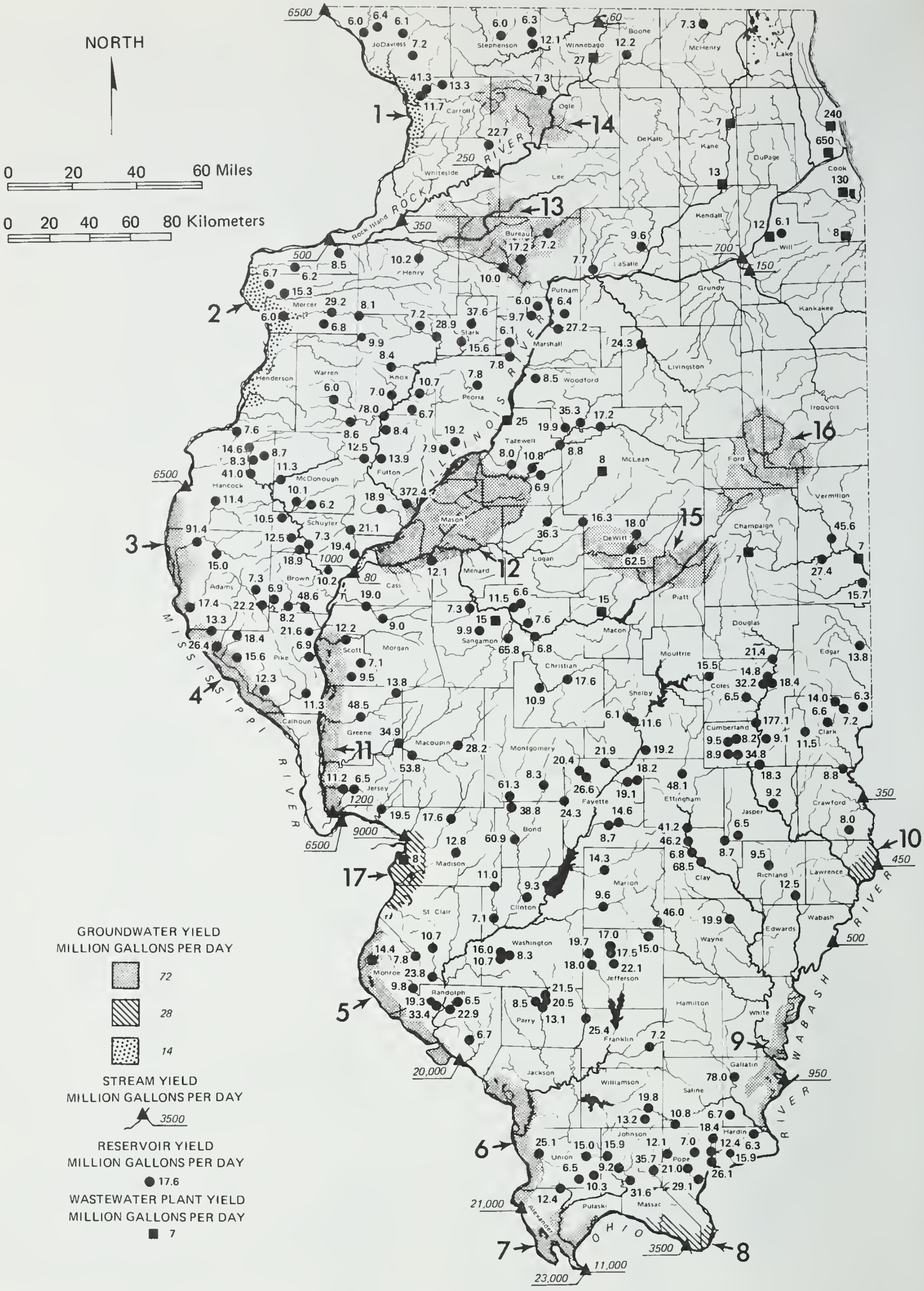

Figure 25. Water available for coal conversion.

TABLE 10—HYDROGEOLOGIC PROPERTIES OF SELECTED GROUND-WATER DEVELOPMENT SITES

Area no. on fig. 25	Location	Estimated river infiltration rate (gpd/acre/ft)	Estimated aquifer permeability (gpd/ft^2)	Estimated average aquifer thickness (ft)	General ground-water conditions
1	Along Mississippi River in Carroll County	450	2,700	100	Water table with induced infiltration from river
2	Along Mississippi River in Henderson County	450	3,500	100	Water table with induced infiltration from river
3	Along Mississippi River north of Quincy in Hancock County	22,500	3,500	100	Water table with induced infiltration from river
4	Along Mississippi River south of Quincy in Pike County	22,500	2,500	100	Water table with induced infiltration from river
5	Along Mississippi River between Valmeyer and Kaskaskia Island	45,000	2,000	90	Water table with induced infiltration from river
6	Along Mississippi River south of Grand Tower Island	45,000	1,800	110	Water table with induced infiltration from river
7	Along Mississippi River in southern Alexander County	45,000	2,000	125	Water table with induced infiltration from river
8	Along Ohio River in Massac County	45,000	2,500	70	Water table with induced infiltration from river
9	Along Wabash River in Gallatin County	22,500	2,000	95	Water table with induced infiltration from river
10	Along Wabash River in Lawrence County	22,500	3,000	85	Water table with induced infiltration from river
11	Along Illinois River centered in Greene County	22,500	2,000	110	Water table with induced infiltration from river
12	Havana Lowlands, centered in Mason County	22,500	(2 values) 2,000 in east 5,000 in west	150	
13	Princeton Valley in Bureau and Whiteside Counties	none	2,000	150	Water table
14	Deep sandstone area centered in Ogle County	none	23	800	
15	Along Buried Mahomet Valley in De Witt and Piatt Counties	none	2,120	120	Leaky artesian
16	Along Buried Mahomet Valley in Ford and Iroquois Counties	none	2,500	150	Leaky artesian
17	East St. Louis area	45,000	2,500	80	Water table with induced infiltration from river

All aquifers, with the exception of those in areas 12 and 17, were assumed to be of a uniform thickness that was based upon the difference between known static water levels in the aquifers and estimated elevations of bedrock at the base of the aquifers. Areas 12 and 17, the Havana Lowlands and the East St. Louis area, were modeled in some detail because data on aquifer thickness were available from previously published reports (Walker, Bergstrom, and Walton, 1965; Bergstrom and Walker, 1956; Schicht, 1965).

In the selected areas general conditions under which ground water occurs are of three types. First, *water table* conditions exist where an aquifer is unconfined at the top and pumped water is derived from gravity drainage of the interstices in the portion of the aquifer being dewatered. Gravity drainage of the interstices decreases the saturated thickness of the aquifer. Under these conditions, water levels in wells become critical after more than half the initial saturated thickness of the aquifer is dewatered.

Second, *leaky artesian* conditions exist where aquifers are overlain by confining beds that impede the vertical flow of the ground water that is recharging the aquifer being pumped. Under these circumstances, critical water levels in wells occur when water levels fall below the bottom of the confining layer. When that happens, the rate of flow through the confining layer reaches a limit as maximum hydraulic gradients are created.

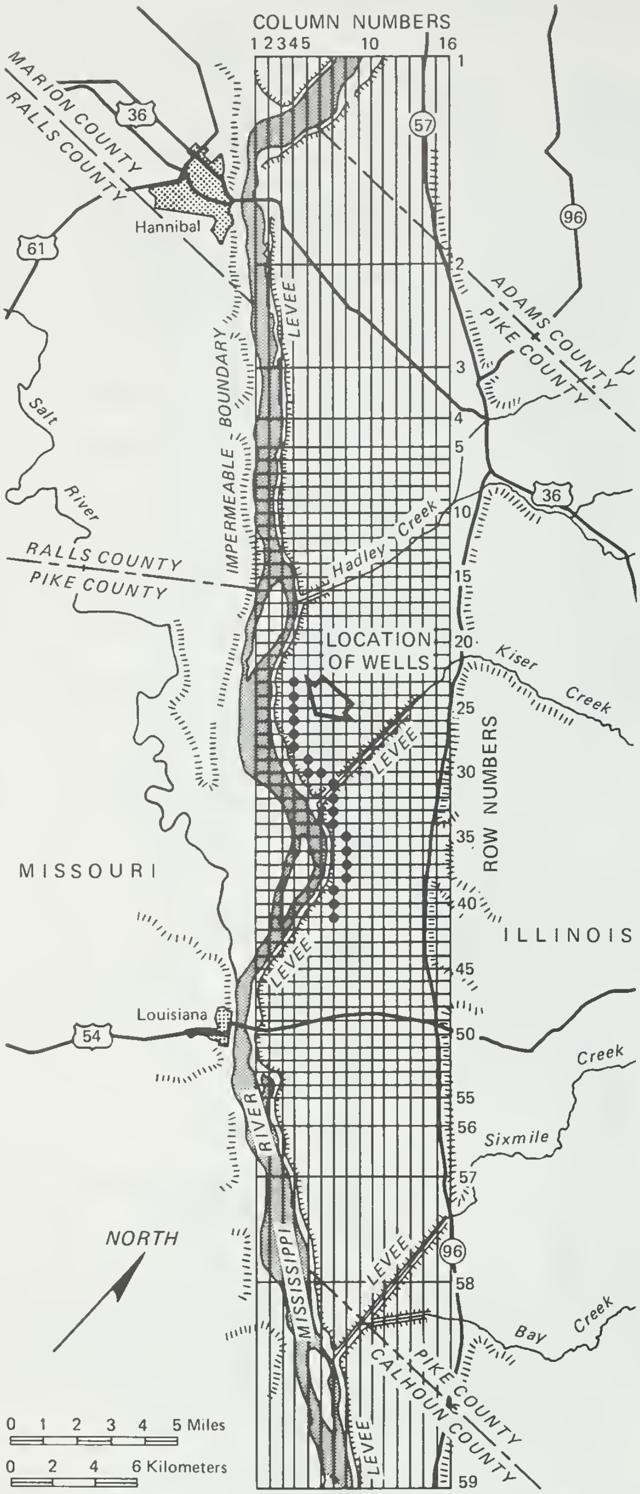

Figure 26. Computer model of discrete elements of aquifer, used for location of wells.

Third, *induced infiltration* conditions exist when wells are pumped in aquifers near, or in hydraulic connection with, streams, rivers, or other surface water bodies. In the course of pumping, water levels in the aquifer may be lowered below surface water levels and the aquifer is recharged by seepage from the surface water body. Induced infiltration conditions can occur in combination with either water table or leaky artesian conditions. However, induced infiltration coexisting with water table conditions is the only combination found in the selected areas. The critical water level in wells for this combination is the same as that for water table conditions.

Digital Computer Models

Digital computer models were developed for studying areas 1 through 13 and 17, and mathematical models were used for studying areas 14 through 16. The digital computer models are capable of simulating two-dimensional flow of ground water in aquifers under water table conditions. The models also can simulate pumpage from wells and the movement of water between surface waters and the groundwater reservoir, thus yielding data on changes in water levels. The equations governing the flow of ground water in models such as those described have been given by Prickett and Lonnquist (1971).

One of the 14 digital models is shown in figure 26. It illustrates the transmission network for a 20-well pumping scheme designed to furnish a 20,000-gpm water supply along the Mississippi River in Pike County, Illinois. The figure shows a grid (finite difference) superposed on a map of the sand and gravel aquifer that lies along the Mississippi River south of Quincy. The aquifer is thus subdivided into discrete elements associated with the numbered rows and columns of the finite difference grid. The edges of the model approximate the sides of the valley that forms the boundary of the aquifer. Sufficient rows in the grid are included upstream and downstream from the area of analysis to prevent the projected water levels from being affected by their position at the edge of the model.

Figure 26 also shows locations of 20 hypothetical wells used to predict the effects of pumping 20,000 gpm of water. The location of the wells was based on (1) reasonably close spacing to avoid mutual interference, (2) present flood control levees (all wells were placed on the land side of the levees), and (3) placement of all wells as close as possible to a river to get maximum induced infiltration from that source of recharge. Most wells were spaced 1,000 to 2,000 feet apart.

The computer produced printed water-level elevations resulting from the various well-pumping schemes. Several computer runs were made for each area to find a suitable scheme for obtaining well yields of 4,000, 10,000, 20,000, and 50,000 gpm (6 to 72 mgd) without creating critically low water levels.

To assure a dependable water supply, the only source of recharge included in the model studies for areas 1 through

1 and 17 was induced infiltration from near-by perennial vers. No allowance for natural recharge from precipita-on as such was included in any of the model simulations.

For areas 12 and 13, which have no rivers near their ell fields, the computer models were designed to simulate ie effects of pumping where the only recharge is from pre-ipitation. Estimates of recharge rates for a year of normal recipitation were based on known recharge rates in hydro-eologically similar areas. To assure that the water supply i areas 12 and 13 would be dependable, allowance was also iade for taking water from storage within the aquifer for sustained 5-year period of no recharge.

The models for areas 1, 2, 8, 10, and 17 showed that ven with reasonable well spacings and the estimated infiltration rates it was not possible to produce 72 mgd of water. reas 1 and 2 were capable of yielding only 14 mgd, while reas 8, 10, and 17 were capable of supplying 28 mgd. reas 3 through 7, 9, and 11 through 13 were estimated to e capable of supporting a 72-mgd water demand.

Mathematical Models

Mathematical models were used to study the feasibility of obtaining the supplies of water needed for coal conversion plants in areas 14 through 16. Mathematical models were used for these areas because previous analyses by the Water Survey could be directly applied to the evaluation of these aquifers.

The mathematical models were of the types outlined by Walker and Walton (1961). Mathematical models involve creation of simplified geometric forms that approximate the configuration of the aquifer. The average hydrogeologic properties of the aquifer and of the confining layer, if any, were selected on the same basis as those for the digital models previously described.

The resulting model is called an idealized aquifer. Analysis is based on the hydrogeologic properties of the idealized aquifer, an analytical technique that simulates the effects of recharge and barrier boundaries on drawdown of water levels in the pumped aquifer (image-well theory), and on an appropriate theoretical ground-water equation.

The results of analyses of areas 14 through 16 made with the mathematical models indicate that these areas are capable of producing the maximum 72 mgd of water needed for a coal conversion plant.

Cost of Ground-Water Development

Analyses of cost for developing ground water in the favorable areas include estimates for wells, pumps, electrical power for pumping, pipelines to a central point, operation, and maintenance. Other possible costs, such as test drilling, tests to determine precise aquifer properties, and land procurement are not included.

Well Costs

Production wells were designed for a maximum development of 1,000 gpm per well (1,390 gpm at areas 15 and 16). Wells in sand and gravel aquifers use screens of 24-inch diameter and from 40 to 100 feet long, whereas those in the Cambrian-Ordovician aquifer of northwestern Illinois (area 14) were 12 inches in diameter. Depths of sand and gravel wells were estimated from elevations taken from topographic and bedrock surface maps, while depths for Cambrian-Ordovician wells were estimated at 1,000 feet (Walton and Csallany, 1962).

Gibb and Sanderson (1969) developed the following cost-to-depth formula for gravel-packed wells finished in sand and gravel and for wells in the Cambrian-Ordovician aquifer:

$$C_{wg} = 680\ d^{0.482} \qquad (1)$$

and

$$C_{wco} = 0.029\ d^{1.87} \qquad (2)$$

where
C_{wg} is the well construction cost for sand and gravel wells and C_{wco} the cost for Cambrian-Ordovician wells in 1966 dollars; d is well depth in feet. Equations (1) and (2) were adjusted to 1973 prices by applying Engineering News-Record Cost Indexes for 1966 and 1973 (Eng. News-Record, 1974). Well construction costs then become:

$$C_{wg} = 1288\ d^{0.482} \qquad (3)$$

and

$$C_{wco} = 0.055\ d^{1.87} \qquad (4)$$

Annual costs for wells were obtained by amortizing capital costs at 6 7/8 percent over an assumed 30-year service life. For this determination a capital recovery factor (CRF) of 0.07985 was used.

Pump Costs

It was assumed that submersible pumps capable of operating at rates of 1,000 gpm would be used. The average pumping lift for pumps within a production field was taken to be the average drawdown (as computed in the digital model), adjusted for dewatering, partial penetration, well loss, nonpumping water level, and a nominal 25-foot head loss to allow for pipeline friction and pressure. To provide stand-by wells, the number of wells (pumps) was increased by 20 percent.

Gibb and Sanderson (1969) determined capital costs for submersible turbine pumps in Illinois to be:

$$C_p = 5.629\ Q^{0.541}\ H^{0.658} \qquad (5)$$

where
C_p is individual pump cost in 1970 dollars, Q is production rate in gpm, and H is average pumping lift (as computed above). When costs are adjusted for 1973 prices, individual pump costs become:

$$C_p = 10.66\ Q^{0.541}\ H^{0.658} \qquad (6)$$

Annual costs for pumps were obtained by amortizing capital costs at 6 7/8 percent over an assumed 15-year service life (CRF = 0.1089).

Electrical Costs

Determinations of electrical cost for production wells were made on the basis of an assumed unit power charge of 1.0 cents per kilowatt hour (kwhr) and on the following expression for pumping energy (Ackermann, 1967):

$$\text{kwhr} = 1.88 \times 10^{-4}\ Qht/E \qquad (7)$$

where
Q is flow in gpm, h is total pumping lift in feet, t is time in hours (assumed to be 1 year or 8760 hr), and E is wire-to-water efficiency (assumed to be 0.5). The annual power cost becomes:

$$C_e = 0.0329\ Qh \qquad (8)$$

Transmission Costs

The construction cost of connecting the well field to the pipeline can be expressed by the equation (Ackermann, 1967):

$$C_t = 4450\ D^{1.2}\ L \qquad (9)$$

where
C_t is capital cost in 1973 dollars, D is pipeline diameter in inches, and L is pipeline length in miles.

Annual operation, maintenance, and repair costs for pipelines were estimated by Singh, Visocky, and Lonnquist (1972) and, adjusted to 1973 prices, appear as:

$$C_{omrt} = 21\ DL \qquad (10)$$

Easement costs for placement of pipelines along rights-of-way (Singh, Visocky, and Lonnquist, 1972), in 1973 dollars, are expressed as:

$$C_{rowt} = 3500\ L \qquad (11)$$

The total annual transmission cost for collecting ground-water supplies is the sum of operation, maintenance, and repair (C_{omrt}) and amortized capital costs (C_t and C_{rowt}). Capital costs were amortized at 6 7/8 percent for a period of 30 years.

Pipe diameters (D) in equations (9) and (10) were selected according to the method used in studies of optimum diameters by Singh (1971).

Cost Summary

Annual and unit costs for water supplies yielding 4,000, 10,000, 20,000, and 50,000 gpm from sand and gravel wells were estimated in 16 areas along the Mississippi, Ohio, Illinois, and Wabash Rivers and in the Princeton and Mahomet bedrock valleys. Similar estimates were made for bedrock wells in area 14 in Ogle County. Unit costs are summarized in table 11. In areas 1, 2, 8, 10, and 17, water is available in limited supplies only, and in area 5 the 50,000-gpm supply requires two 25,000-gpm fields whose centers are 15.7 miles apart. Area 17 also needs two well fields.

TABLE 11—ESTIMATED COST OF GROUND-WATER SUPPLY AT SELECTED SITES

	Estimated cost of supply (¢/1,000 gal)			
Area	4,000 gpm	10,000 gpm	20,000 gpm	50,000 gpm
1	1.17	1.38	N. A.*	N. A.
2	1.20	1.45	N. A.	N. A.
3	1.43	1.86	2.27	3.28
4	1.41	1.87	2.33	3.36
5	1.22	1.44	1.73	4.43†
6	1.46	1.85	2.21	3.28
7	1.12	1.27	1.57	1.73
8	1.00	1.21	1.47	N. A.
9	1.10	1.30	1.85	2.01
10	0.92	1.22	1.47	N. A.
11	1.08	1.28	1.49	1.68
12	1.24	1.61	2.05	2.76
13	1.55	2.00	2.55	2.98
14‡	3.58	5.31	6.49	8.46
15	1.56	1.87	2.32	1.92
16	1.69	1.99	2.40	2.16
17**	1.42	1.76	2.27	N. A.
Average (excluding site 14)	1.29	1.59	2.00	2.69

* *Supply not available.*

† *From two 25,000-gpm well fields 15.7 miles apart.*

‡ *Bedrock aquifer.*

***From two 10,000-gpm well fields 10 miles apart.*

TABLE 12–AVERAGE AMOUNTS OF MINERAL CONSTITUENTS IN GROUND WATER AT SELECTED SITES

(mg/l)

Area	Total dissolved solids	Hard-ness	Alka-linity	Fe	Mn	Cl	F	NO_3	SO_4	Temp. (°F)
1	233	172	116	1.1	0.2	0.9	0.3	26.4	28.9	53.2
2	261	223	179	0.8	0.3	6.9	0.2	9.4	29.1	55.3
3	338	301	294	5.3	1.5	7.1		5.8	7.4	
4	305	254	227	3.9	1.7	13.6	0.4	2.3	42.2	56.4
5	515	429	307	13.4	1.0	48	0.3	7.9	72	56.3
6	347	262	251	2.0	0.2	6.4	0.1	6.5	35.6	58.3
7	377	306	315	3.6	0.2	10.1	0.2	5.6	19.1	58.5
8	134	102	103	6.1	0.1	6.3	0.3	1.9	12.0	60
9	510	342	363	1.0	0.2	54.8	0.2	1.4	9.8	59.3
10	359	266	250	0.7	0.1	11.6	0.1	11.1	55.0	
11	428	380	285	0.1	Tr	15.6	0.1	11.8	43.2	56
12	322	285	236	1.6		6.4	0.1	10.0	42.2	55.4
13	360	263	332	3.3	0.2	1.6	0.4	0.9	0.2	54.0
14	299	295	285	0.4	0.03	2.0	0.7	0.7	25.3	51.4
15	494	306	409	1.4	0.04	46.3	0.4	1.1	1.2	56.2
16	408	332	364	1.1	0.03	4.1	0.2	1.8	19.4	55
17	504	409	296	7.4	0.40	17.6	0.4	1.8	113.6	57.5

Excluding area 14, which has bedrock aquifers, unit osts in areas 1 to 17 (sand and gravel wells) ranged from .92 to 1.69 cents per 1,000 gallons for a 4,000-gpm suply and from 1.68 to 4.43 cents per 1,000 gallons for a 0,000-gpm supply. Unit costs generally increase with roduction rate, there being no economies of scale involved n the cost factors considered. It is assumed that no treatnent will be given to the water. Average costs in areas 1 to 3 and 15 to 17 for supplies of 4,000, 10,000, 20,000, and 0,000 gpm were 1.29, 1.59, 2.00, and 2.69 cents per 1,000 allons, respectively. Corresponding costs from the deep andstone aquifer (area 14) were approximately three times s great, 3.58, 5.31, 6.49, and 8.46 cents per 1,000 gallons. While other unit costs in areas 1 to 13 and 15 to 17 remain elatively stable, average transmission costs rise from 31.5 ercent of the total costs for 4,000-gpm supplies to 56.2 ercent of the total for 50,000-gpm supplies. For Camrian–Ordovician wells, such as that in area 14, electrical osts are the largest unit cost. They decrease as the gallons er minute rate increases from 61.2 to 44.3 percent of the otal, but transmission costs increase from 16.7 to 43.9 perent of the total cost.

Ground-Water Quality

The chemical quality of water supplies at the 17 study reas can be estimated from mineral analyses of near-by xisting ground-water supplies. Such analyses on file at the llinois State Water Survey were averaged for each area to etermine the average quality that might be expected there. The average values of chemical concentration and temperature are summarized in table 12.

The review revealed that water in most of the areas studied is of fairly good quality, with total dissolved solids averaging between 134 and 515 milligrams per liter (mg/l). It has moderate to high hardness, averaging between 102 and 429 mg/l. Iron also is present in considerable concentration, between 0.1 and 13.4 mg/l. Average water temperature ranges from 51.4° to 60° F, the cooler temperatures appearing in the northern areas and the warmer ones in southern areas.

Legal Aspects of Ground-Water Development

It is beyond the scope of this report to deal more than briefly with Illinois water law, but several excellent sources are available as described in *Water for Illinois, A Plan for Action* (Board of Economic Development, 1967). The Illinois Supreme Court has adopted the English common law rule for cases involving percolating ground water. In essence, the rule states that the owner of the land owns all the percolating water underlying his land.

AVAILABILITY OF SURFACE WATER FOR COAL CONVERSION

Not only is Illinois bordered by the Mississippi, the Ohio, and the Wabash Rivers and by Lake Michigan, but it is also internally drained by the Rock, the Illinois, the Sangamon, the Kaskaskia, the Big Muddy, the Embarras, and the Little Wabash Rivers, as well as many smaller streams. In addition, Illinois has 368 bodies of water of 40 acres or more.

Streamflow is continuously recorded along the streams of the state. These flow data are collected and published by the U. S. Geological Survey (1974), half the cost being provided by a state sponsor. The Illinois State Water Survey is the largest of the state sponsors of this program. In 1971 records were kept at 167 locations. Continuous streamflow records for the 25-year period 1950 through 1974 are available from about 100 gaging stations.

The average runoff to streams is about 9 inches a year in most of central Illinois and about 15 inches in southern Illinois. Runoff is a major water resource because it can be taken directly from a stream and used immediately or it can be stored in a reservoir and used as needed.

One important means of conserving water is to capture flood runoff and keep it in a reservoir for use in dry seasons. Reservoir lakes can also be used for recreation and other purposes. Illinois has several large reservoirs, and more are being planned or constructed; a large potential remains for the development of additional impoundments. Man-made lakes or reservoirs have been developed throughout the state for various purposes. Some of the larger existing lakes are listed in table 13.

Except for lakes in the valleys of the larger streams, natural lakes are confined to the northeastern portion of Illinois. They are the result of juvenile drainage following the last glacial period. Most of them are in the Chain O'Lakes region in Lake and McHenry Counties.

Bodies of water of 40 acres or more have a total surface area of 138,317 acres. The northern section of the state contains 117 such lakes, 47 of them in Lake County. Of the 128 bodies of water in the north-central section, 27 are in Mason County. The south-central section contains 72 lakes, 11 in Calhoun County and 11 in Macoupin County. Of the 51 lakes in the southern section, Franklin and Williamson Counties have 9 each. A small portion of the total water surface and storage area is made up of many ponds, lakes, and reservoirs of less than 40 acres.

Four potential sources of surface water were studied to locate possible water supplies for coal conversion—water flowing in rivers and streams, water impounded in existing reservoirs, surface water that could be impounded in reservoirs, and treated wastewater.

Legal Aspects of Surface Water and Lake Michigan

For streams within the state, the Illinois Supreme Court has subscribed to the doctrine of riparian rights with respect to the reasonable use of water in natural water courses.

The diversion of water from Lake Michigan by Illinois is limited to 3,200 cubic feet per second (cfs) by decree of the U. S. Supreme Court (Northeastern Illinois Planning Commission, 1974). At present this water is being used for water supply, chiefly by Chicago, and to augment flow in the Chicago Sanitary and Ship Canal and the Calumet-Sag Canal. This report does not evaluate the potential application of Lake Michigan water for coal conversion.

TABLE 13—LARGE MAN-MADE LAKES OF ILLINOIS

Purpose and name	Near-by city	Lake capacity (million gal)
Flood Control and Water Supply		
Carlyle Lake	Carlyle	92,204
Lake Shelbyville	Shelbyville	68,669
Rend Lake	Benton	60,167
Recreation and Wildlife		
Crab Orchard Lake	Carbondale	19,901
Little Grassy Lake	Carbondale	8,386
Devils Kitchen Lake	Carbondale	9,122
Power Plant Supply		
Impounded Lakes		
Lake of Egypt	Marion	13,863
Sangchris Lake	Springfield	11,403
Coffeen Lake	Coffeen	7,179
Side-Channel Lakes		
Lake Baldwin	Baldwin	7,982
Con-Ed Lake	La Salle	6,540
City Water Supply		
Lake Springfield	Springfield	18,434
Lake Decatur	Decatur	7,278
Lake Bloomington	Bloomington	2,628
Evergreen Lake	Bloomington	4,473
Lake Kinkaid	Murphysboro	25,738
Lake Vermilion	Danville	1,776
Lake Taylorville	Taylorville	3,183
Lake Sara	Effingham	4,496
Lake Lou Yaeger	Litchfield	1,430

Treated Wastewater

Treated wastewater, or sewage effluent of acceptable quality, is another possible source of water for coal conversion. All cities operating wastewater treatment plants are required by the Illinois Environmental Protection Agency to submit monthly operation reports. These reports show the amount of wastewater in gallons per day leaving the plant after treatment, any wastewater bypassed untreated during rains in places where the storm and sanitary sewer systems are combined, and quality parameters such as biologic oxygen demand (BOD) and concentration of suspended solids.

The state EPA field offices supplied information on effluent flow for the year 1970, as well as for a few earlier years. Study of this information indicated that 15 municipalities in the state have 7-day low-flow sewage effluents that are within the range of the defined water consumption

TABLE 14—MUNICIPAL PLANTS WITH 7-DAY LOW-FLOW EFFLUENT OF 6 MGD OR MORE IN 1970

(Locations in figure 25)

Town or plant	County	7-day low-flow effluent (mgd)
Rockford	Winnebago	27
Aurora	Kane	13
Elgin	Kane, Cook	7
Bloom Township	Cook	8
Joliet	Will	12
Northside	Cook	240
West Southwest	Cook	650
Calumet	Cook	130
Peoria	Peoria	25
Springfield	Sangamon	15
Decatur	Macon	15
Bloomington	McLean	8
East St. Louis	St. Clair	8
Danville	Vermilion	7
Urbana	Champaign	7

needs for coal conversion. The plants are listed in table 14 and their locations are shown on figure 25.

Water from Rivers

Available flow records for the principal rivers in and bounding Illinois were used to estimate the minimum daily flow that could be expected during a 50-year period (fig. 25). These quantities of water are considered as being available for use by coal conversion plants.

The Mississippi River on the western edge of Illinois was estimated to have a minimum flow of 6,500 mgd, an amount almost 100 times greater than the maximum amount of water (72 mgd) assumed to be needed by one coal conversion plant. Along the southwestern part of Illinois, minimum flows in the Mississippi River rise to between 20,000 and 23,000 mgd. Along the Ohio River, in southern Illinois, the range of flow is from 3,500 mgd to 11,000 mgd. The Wabash River bounding southeastern Illinois has a minimum flow of between 350 and 950 mgd. The Illinois River of central Illinois has flows of 700 mgd at its upper extremity, about 1,000 mgd near Peoria, and 1,200 mgd at its confluence with the Mississippi River. All these amounts greatly exceed the amount of water used by one coal conversion plant. Values for the Rock River in northern Illinois range from 60 mgd near the Wisconsin state line to 500 mgd where the Rock River empties into the Mississippi River.

Existing Reservoirs

A number of relatively large reservoirs already exist in Illinois (table 13), but the water supply of most of them has already been committed to public supply. Only two of these present a possible, but not probable, source for conversion plants.

Rend Lake in Franklin County can provide a water supply of 40 mgd, which is already committed to the Rend Lake Intercity Water System. It is unlikely that water can be furnished for any additional use at present. The state of Illinois owns part of the water supply in Lake Shelbyville, Shelby County, and a supply of 14 mgd could be provided for coal conversion if the state so decided. The state also owns part of the water supply in Carlyle Lake in Clinton County. This lake could provide a water supply of 29 mgd. These two are the only existing reservoirs that might furnish a water supply for coal conversion.

Potential Reservoirs

From 1962 to 1967, a detailed study of Illinois was made by the State Water Survey to locate potential reservoir sites. Some 1,200 potential sites were examined, 800 of which seemed favorable for reservoir construction. Detailed information was published on the physical aspects of each of these sites. Separate reports contain results for southern Illinois (Roberts et al., 1962), south-central Illinois (Dawes and Terstriep, 1966a), north-central Illinois (Dawes and Terstriep, 1966b), and northern Illinois (Dawes and Terstriep, 1967). Most of the reservoir sites described in these four reports are of a size suitable for public water supply in Illinois but are not large enough to supply a coal conversion plant.

To evaluate the potential man-made reservoirs as sources of water for coal conversion, the Water Survey made a further study of all potential reservoir sites in Illinois. The study found 228 locations where a potential reservoir capable of supplying more than 6 mgd of water could be built. Table D (Appendix 1) gives data for each of the sites. The yield of a reservoir in million gallons per day (table D) would use only half the reservoir capacity during a drouth that had a recurrence interval of 40 years. Recreational use of the lake could therefore continue during the drouth. The yield shown in the table is the amount of water a reservoir could furnish for use by coal conversion plants. In table D there are 266 entries for the 228 sites selected because two sizes of reservoirs have been proposed for some sites, noted in the table as, for instance, 26 and 26A. Sites with letter suffixes are different versions of the sites with plain numbers, but the general location is the same.

The potential reservoirs that could be built at the 228 locations (table D) indicate the vast water resources available for coal conversion plants in Illinois. Each one of the possible reservoirs could supply at least the minimum quantity of water required for one coal conversion plant (6 mgd).

Cost of Potential Reservoirs

A typical cost analysis was made for selected reservoir capacities in different geographic locations of the state. Computation of the estimated project cost of the reservoirs followed the method proposed by Dawes and Wathne (1968). The formula given by Dawes and Wathne (1968) is based on a 1964 cost level, but the Handy-Whitman Index (1973) was used to bring the cost to a 1972 level. The price of land is based on the land values in Illinois cited in the Agricultural Census of 1969, converted to 1972 level by the cost index numbers of Illinois farmland values supplied by Dr. F. J. Reiss, Professor of Land Economics and Extension Specialist in Farm Management and Tenancy of the University of Illinois (personal communication, 1975).

The original equation for cost of reservoirs proposed by Dawes and Wathne (1968) is based on data for reservoirs constructed in Illinois since 1946 that were collected from consulting engineers, private and municipal water utilities, and state and Federal agencies. The project cost used here is the sum of the cost of construction, engineering and legal services, contingencies, and land. The term "construction cost" in the analysis encompasses costs of land clearing, dam and spillway construction, and relocations. Engineering and legal services were added as a fixed percentage—15 percent of construction cost. Contingencies were added as 10 percent of the construction cost. The amount of land required for a project was determined to be 50 percent more than the actual normal surface area of the pool. The reservoir project cost is estimated by the following equation:

$$P_c = C_1 C + C_2 L_a k$$

where

P_c = total project cost in dollars

C_1 = 1.25, a combined constant accounting for engineering and legal services (15 percent of C) plus contingencies (10 percent of C)

C = $4287 S^{0.54}$, the construction cost (S = storage capacity in acre-feet)

C_2 = 1.50, total required land area, 50 percent more area than needed for normal surface area of pool

L_a = $0.23 S^{0.87}$, the required lake area

k = land cost expressed in dollars per acre

The measure of dispersion in both the construction cost, C, and the lake area required, L_a, is given by the respective standard deviations expressed in percentages as 70.9 and 39.0. For estimates of project cost, values one standard deviation above the regression line were selected. This implies that, on the average, the actual values in excess of the estimated cost is expected only 16 percent of the time. In simplified form, the appropriate substitutions in the cost equation provide:

$$P_c = 9161 S^{0.54} + 0.49 S^{0.87} k$$

The ratio in the Handy-Whitman Cost Index (Whitman et al., 1973) for impounding reservoirs between 1964 and 1972 is:

$$(282.2)/(176.5) = 1.60$$

Therefore, the final equation for project cost is:

$$\begin{aligned} P_c &= (9161)(1.598867) S^{0.54} + 0.49 S^{0.87} k \\ &= 14{,}647 S^{0.54} + 0.49 S^{0.87} k \qquad (12) \end{aligned}$$

Equation 12 was used to compute the cost of potential reservoir sites, and the results are shown in figure 27.

As can be seen in figure 27, the cost of potential reservoirs varies with geographic location in Illinois. Costs are higher in northern Illinois than in southern, principally because land costs are higher in the northern part of the state. The project cost of potential reservoirs also varies with the reservoir capacity and ranges from about 1.8 million dollars for a reservoir capacity of 5,000 acre-ft to about 35 million dollars for a reservoir capacity of 500,000 acre-ft (fig. 27).

The relation between the reservoir yield and the reservoir capacity is given in figure 28, which provides a rough way of estimating the net yield of a reservoir, based upon reservoir capacity only. Figures 27 and 28 can be used together to relate project costs and reservoir net yield.

Quality of Surface Water

When a water supply is being planned for a coal conversion plant or for municipal, agricultural, industrial, or other uses, it is not enough to know that the water is merely potable. The amount and the kind of minerals in the water also must be known if an estimate of the cost of water treatment is to be made.

Available information and interviews with several engineers and researchers in this field reveal that no general standards can be set for the minimum water quality that is required by the various coal conversion processes. For that reason, existing surface-water qualities in Illinois are described here.

The parameters selected for defining mineral quality in this report were chosen because of their effect on general municipal and industrial use. No assessment is made here of the sanitary quality of the water.

Water dissolves minerals and other substances. The degree to which solution takes place depends on the type of mineral involved, the time of contact, and, in some cases, the presence or absence of dissolved oxygen. For example, Illinois surface waters in rivers and lakes seldom contain dissolved iron because they contain dissolved oxygen. Iron

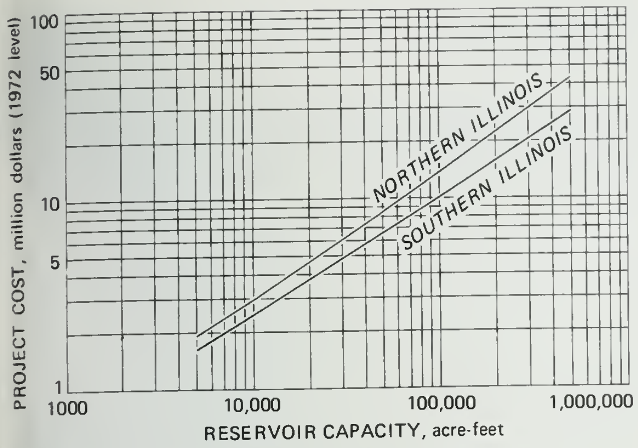

Figure 27. Reservoir capacity and cost.

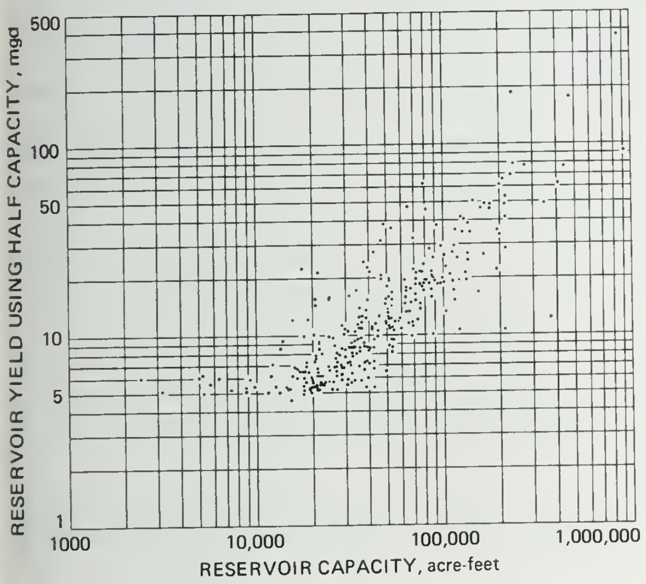

Figure 28. Relation between reservoir yield and reservoir capacity.

may be present as suspended iron oxide or in suspended silt, but it is not dissolved. On the other hand, well waters seldom contain dissolved oxygen and iron is present in the water of about three of every four wells in a concentration of more than 0.3 mg/l, which is sufficient to cause staining.

The minerals in ground water are related to the associated geologic formation. The minerals in surface water are generally those of the surface soil, although many streams are occasionally fed by ground water. Other minerals are added through public, industrial, and agricultural use of water.

For most subsurface waters, chemical analysis of a single sample is sufficient to give an accurate evaluation of the quality of the water produced from a given well. However, because the quality of the water in a stream varies almost continuously, a series of analyses must be made on numerous samples obtained by a regulated sampling program.

Most waters in Illinois are suitable for agricultural use if the mineral content is satisfactory for municipal use and if the sodium adsorption ratio (the total dissolved minerals minus the hardness, divided by 5 times the square root of the hardness) does not exceed 10. A ratio of more than 20 to 25 is generally unsatisfactory.

The surface-water quality for various parts of the state is summarized in table E (Appendix 1). Data were analyzed from samples collected by the State Water Survey in 29 watersheds from 44 sampling locations. Samples were generally collected monthly for a period of four to five years at each sampling station. Locations of the sampling stations are shown in figure 29.

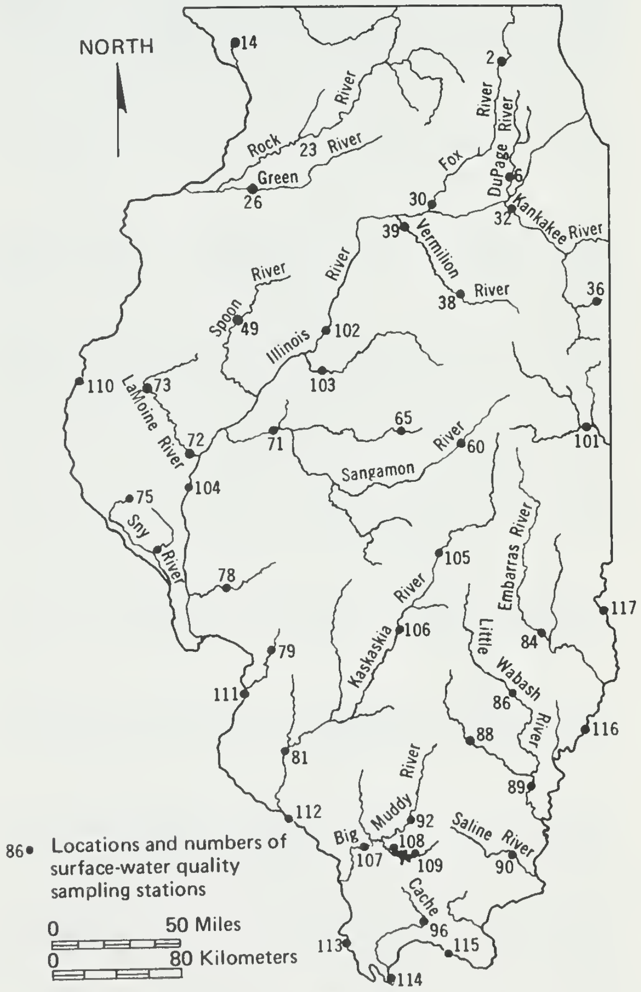

Figure 29. Location of water quality sampling stations.

CONCLUSIONS

Illinois is rich in water in the quantities needed for coal conversion. Water could be supplied to a plant anywhere along the major rivers—the Mississippi, Ohio, Wabash, Illinois or Rock. The minimum flow in the Mississippi River, as shown on the accompanying map (pl. 3), could supply numerous coal conversion plants, each using water at a rate of 72 mgd.

At 228 locations (pl. 3) at least 6 mgd could be supplied to a coal conversion plant from a man-made reservoir. At 17 locations a system of wells could be constructed to provide a water supply of at least 14 mgd for coal conversion.

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APPENDIX 1

TABLES

TABLE A—SUMMARY OF COAL RESERVES 42 OR MORE INCHES THICK IN THE HERRIN (NO. 6) AND HARRISBURG-SPRINGFIELD (NO. 5) SEAMS

County	Coal seam	Coal reserves (thousands of tons) by average thickness							County totals*			County averages†	
		4 ft	5 ft	6 ft	7 ft	8 ft	9 ft	10+ ft	Thousands of tons	Area of coal remaining (sq mi)	Area‡ mined out (sq mi)	Average thick-ness (ft)	Av. tons per sq mi (in thou-sands)
Bond	6	175,103	786,247	542,461	625,981	114,365	13,078	0	2,257,235	344.28	4.12	5.69	6,556
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		175,103	786,247	542,461	625,981	114,365	13,078	0	2,257,235				
Bureau	6	189,556	355,843	21,427	0	0	0	0	566,826	106.01	4.64	4.64	5,347
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		189,556	355,843	21,427	0	0	0	0	566,826				
Cass	6	0	0	0	0	0	0	0	0	0.0	0.0		
	5	41,564	38,477	66,355	0	0	0	0	146,396	25.30	0.0	5.02	5,786
Totals		41,564	38,477	66,355	0	0	0	0	146,396				
Champaign	6	57,180	6,409	0	0	0	0	0	63,589	13.52	0.0	4.08	4,703
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		57,180	6,409	0	0	0	0	0	63,589				
Christian	6	200,171	266,621	460,738	605,485	1,595,682	368,293	52,410	3,549,400	444.69	91.13	6.93	7,982
	5	131,633	914,911	168,860	0	0	0	0	1,215,404	211.83	0.70	4.98	5,738
Totals		331,804	1,181,532	629,598	605,485	1,595,682	368,293	52,410	4,764,804				
Clark	6	0	0	0	0	0	0	0	0	0.0	0.0		
	5	423,655	759,097	0	0	0	0	0	1,182,752	223.73	0.0	4.59	5,287
Totals		423,655	759,097	0	0	0	0	0	1,182,752				
Clay	6	583,716	360,935	109,516	0	0	0	0	1,054,167	205.18	0.0	4.46	5,138
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		583,716	360,935	109,516	0	0	0	0	1,054,167				
Clinton	6	90,536	858,601	610,684	668,059	666,902	100,339	15,831	3,010,952	423.32	13.42	6.17	7,113
	5	472	0	0	0	0	0	0	472	0.10	0.0	4.00	4,608
Totals		91,008	858,601	610,684	668,059	666,902	100,339	15,831	3,011,424				
Coles	6	175,483	0	0	0	0	0	0	175,483	38.08	0.0	4.00	4,608
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		175,483	0	0	0	0	0	0	175,483				
Crawford	6	92,185	19,287	0	0	0	0	0	111,472	23.35	0.0	4.14	4,773
	5	259,915	13,541	4,562	0	0	0	0	278,018	59.42	0.0	4.06	4,679
Totals		352,100	32,828	4,562	0	0	0	0	389,490				
Cumberland	6	33,186	359,679	19,773	0	0	0	0	412,638	72.51	0.0	4.94	5,691
	5	62,484	59,789	0	0	0	0	0	122,273	23.94	0.0	4.43	5,107

De Witt	6	0	0	0	0	0	0	0	0	0.0	0.0		
	5	1,394,292	69,890	0	0	0	0	0	1,464,182	314.71	0.0	4.04	4,652
Totals		1,394,292	69,890	0	0	0	0	0	1,464,182				
Douglas	6	154,234	154,096	252,387	74,944	0	0	0	635,661	106.03	5.54	5.20	5,995
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		154,234	154,096	252,387	74,944	0	0	0	635,661				
Edgar	6	451,363	164,486	129,851	5,484	0	0	0	751,184	145.98	0.0	4.47	5,146
	5	427,643	0	0	0	0	0	0	427,643	92.80	1.40	4.00	4,608
Totals		879,006	164,486	129,851	5,484	0	0	0	1,178,827				
Edwards	6	339,800	75,589	16,112	0	0	0	0	431,501	89.20	0.0	4.20	4,838
	5	157,249	151,635	185,539	148,638	78,775	10,575	7,258	739,669	115.92	0.0	5.54	6,381
Totals		497,049	227,224	201,651	148,638	78,775	10,575	7,258	1,171,170				
Effingham	6	418,299	414,317	188,218	0	0	0	0	1,020,834	189.94	0.0	4.67	5,375
	5	807,967	373,478	0	0	0	0	0	1,181,445	240.18	0.0	4.27	4,919
Totals		1,226,266	787,795	188,218	0	0	0	0	2,202,279				
Fayette	6	161,744	1,136,909	1,273,194	672,067	157,974	0	0	3,401,888	517.16	0.0	5.71	6,578
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		161,744	1,136,909	1,273,194	672,067	157,974	0	0	3,401,888				
Franklin	6	59,711	184,546	463,011	492,142	193,727	163,791	26,937	1,583,865	212.17	150.94	6.48	7,465
	5	1,337,102	476,175	89,364	0	0	0	0	1,902,641	385.77	0.0	4.28	4,932
Totals		1,396,813	660,721	552,375	492,142	193,727	163,791	26,937	3,486,506				
Fulton	6	234,696	0	0	0	0	0	0	234,696	50.93	6.24	4.00	4,608
	5	334,860	293,818	21,704	0	0	0	0	650,382	126.82	81.91	4.45	5,128
Totals		569,556	293,818	21,704	0	0	0	0	885,078				
Gallatin	6	402,397	119,722	22,378	7,741	0	0	0	552,238	112.31	2.11	4.27	4,917
	5	505,402	680,624	36,081	0	0	0	0	1,222,107	233.06	7.90	4.55	5,244
Totals		907,799	800,346	58,459	7,741	0	0	0	1,774,345				
Greene	6	27,147	667	28	0	0	0	0	27,842	6.01	0.0	4.02	4,632
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		27,147	667	28	0	0	0	0	27,842				
Hamilton	6	592,976	614,598	491,903	273,987	108,064	1,866	0	2,083,394	352.43	0.0	5.13	5,911
	5	468,350	803,756	617,039	184,924	58,478	1,987	0	2,134,534	359.92	0.0	5.15	5,931
Totals		1,061,326	1,418,354	1,108,942	458,911	166,542	3,853	0	4,217,928				
Henry	6	187,294	0	0	0	0	0	0	187,294	40.65	2.53	4.00	4,608
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		187,294	0	0	0	0	0	0	187,294				

(Continued on next page)

TABLE A—*Continued*

County	Coal seam	Coal reserves (thousands of tons) by average thickness							County totals*			County averages†	
		4 ft	5 ft	6 ft	7 ft	8 ft	9 ft	10+ ft	Thousands of tons	Area of coal remaining (sq mi)	Area‡ mined out (sq mi)	Average thick-ness (ft)	Av. tons per sq mi (in thou-sands)
Jackson	6	16,439	23,796	28,063	7,961	10,561	16,341	0	103,161	15.47	10.15	5.79	6,669
	5	163,722	86,170	0	0	0	0	0	249,892	50.49	3.38	4.30	4,949
Totals		180,161	109,966	28,063	7,961	10,561	16,341	0	353,053				
Jasper	6	441,899	1,067,777	751,000	0	0	0	0	2,260,676	389.93	0.0	5.03	5,798
	5	531,336	17,626	0	0	0	0	0	548,962	118.37	0.0	4.03	4,638
Totals		973,235	1,085,403	751,000	0	0	0	0	2,809,638				
Jefferson	6	504,099	584,731	748,799	305,946	128,845	41,332	52,402	2,366,154	379.70	22.17	5.41	6,232
	5	1,690,091	807,274	139,683	2,984	0	0	0	2,640,032	527.50	0.0	4.34	5,005
Totals		2,194,190	1,392,005	888,482	308,930	128,845	41,332	52,402	5,006,186				
Jersey	6	28,949	0	0	0	0	0	0	28,949	6.28	0.0	4.00	4,608
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		28,949	0	0	0	0	0	0	28,949				
Knox	6	214,687	0	0	0	0	0	0	214,687	46.59	18.57	4.00	4,608
	5	81,654	0	0	0	0	0	0	81,654	17.72	3.82	4.00	4,608
Totals		296,341	0	0	0	0	0	0	296,341				
La Salle	6	63,839	11,903	0	0	0	0	0	75,742	15.92	11.01	4.13	4,758
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		63,839	11,903	0	0	0	0	0	75,742				
Lawrence	6	266,417	0	0	0	0	0	0	266,417	57.82	0.0	4.00	4,608
	5	371,213	205,045	8,328	0	0	0	0	584,586	117.36	0.0	4.32	4,981
Totals		637,630	205,045	8,328	0	0	0	0	851,003				
Livingston	6	24,653	0	0	0	0	0	0	24,653	5.35	2.85	4.00	4,608
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		24,653	0	0	0	0	0	0	24,653				
Logan	6	0	0	0	0	0	0	0	0	0.0	0.0		
	5	555,425	907,524	981,418	687	0	0	0	2,445,054	420.16	8.24	5.05	5,819
Totals		555,425	907,524	981,418	687	0	0	0	2,445,054				
McLean	6	0	0	0	0	0	0	0	0	0.0	0.0		
	5	1,960,467	118,652	0	0	0	0	0	2,079,119	446.05	1.00	4.05	4,661
Totals		1,960,467	118,652	0	0	0	0	0	2,079,119				
Macon	6	82,195	27,732	12,505	5,214	445	0	0	128,091	25.16	0.0	4.42	5,092
	5	783,681	635,131	104,331	0	0	0	0	1,523,143	295.43	3.02	4.48	5,156
Totals		865,876	662,863	116,836	5,214	445	0	0	1,651,234				

Macoupin	6	633,538	586,183	833,410	1,173,167	410,252	19,620	4,378	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		633,538	586,183	833,410	1,173,167	410,252	19,620	4,378	3,660,548				
Madison	6	360,869	448,342	730,425	456,979	55,637	0	0	2,052,252	324.53	53.24	5.49	6,324
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		360,869	448,342	730,425	456,979	55,637	0	0	2,052,252				
Marion	6	289,937	361,604	110,031	68,676	1,732	0	0	831,980	150.32	10.02	4.80	5,535
	5	1,702,153	462,720	9,678	0	0	0	0	2,174,551	451.12	0.01	4.18	4,820
Totals		1,992,090	824,324	119,709	68,676	1,732	0	0	3,006,531				
Menard	6	0	0	0	0	0	0	0	0	0.0	0.0		
	5	15,315	254,914	1,232,549	31,692	0	0	0	1,534,470	229.83	2.91	5.80	6,677
Totals		15,315	254,914	1,232,549	31,692	0	0	0	1,534,470				
Monroe	6	9,719	258	0	0	0	0	0	9,977	2.15	0.0	4.02	4,632
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		9,719	258	0	0	0	0	0	9,977				
Montgomery	6	117,591	199,460	440,668	1,357,263	1,526,642	57,904	9,854	3,709,382	464.30	43.86	6.93	7,989
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		117,591	199,460	440,668	1,357,263	1,526,642	57,904	9,854	3,709,382				
Morgan	6	36,352	54,547	0	0	0	0	0	90,899	17.36	0.0	4.55	5,236
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		36,352	54,547	0	0	0	0	0	90,899				
Moultrie	6	3,917	152,467	103,956	0	0	0	0	260,340	42.36	0.68	5.33	6,146
	5	102,161	0	0	0	0	0	0	102,161	22.17	0.0	4.00	4,608
Totals		106,078	152,467	103,956	0	0	0	0	362,501				
Peoria	6	1,035,169	0	0	0	0	0	0	1,035,169	224.65	7.75	4.00	4,608
	5	523,838	212,564	0	0	0	0	0	736,402	150.58	34.02	4.25	4,890
Totals		1,559,007	212,564	0	0	0	0	0	1,771,571				
Perry	6	41,184	258,409	658,334	877,852	230,789	2	0	2,066,570	282.95	72.11	6.34	7,304
	5	287,102	24,062	0	0	0	0	0	311,164	66.48	4.61	4.06	4,680
Totals		328,286	282,471	658,334	877,852	230,789	2	0	2,377,734				
Piatt	6	0	0	0	0	0	0	0	0	0.0	0.0		
	5	1,036,517	0	0	0	0	0	0	1,036,517	224.94	0.0	4.00	4,608
Totals		1,036,517	0	0	0	0	0	0	1,036,517				
Putnam	6	16,220	6,912	0	0	0	0	0	23,132	4.72	0.0	4.25	4,901
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		16,220	6,912	0	0	0	0	0	23,132				

(Concluded on next pages)

TABLE A–*Concluded*

County	Coal seam	Coal reserves (thousands of tons) by average thickness							County totals*			County averages†	
		4 ft	5 ft	6 ft	7 ft	8 ft	9 ft	10+ ft	Thousands of tons	Area of coal remaining (sq mi)	Area‡ mined out (sq mi)	Average thick- ness (ft)	Av. tons per sq mi (in thou- sands)
Randolph	6	15,030	52,666	267,942	62,835	0	0	0	398,473	58.96	30.24	5.87	6,758
	5	105,431	6,797	0	0	0	0	0	112,228	24.06	2.78	4.05	4,665
Totals		120,461	59,463	267,942	62,835	0	0	0	510,701				
Richland	6	675,791	599,156	97,498	0	0	0	0	1,372,445	264.78	0.0	4.50	5,183
	5	529,513	1,387	0	0	0	0	0	530,900	115.15	0.0	4.00	4,610
Totals		1,205,304	600,543	97,498	0	0	0	0	1,903,345				
St. Clair	6	108,749	140,802	537,296	929,395	598,890	3,852	0	2,318,984	306.39	89.91	6.57	7,569
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		108,749	140,802	537,296	929,395	598,890	3,852	0	2,318,984				
Saline	6	283,558	456,883	285,839	14,363	3,176	0	0	.1,043,819	184.34	6.41	4.92	5,663
	5	138,776	444,348	245,002	52,794	4,332	0	0	885,252	149.72	80.80	5.13	5,913
Totals		422,334	901,231	530,841	67,157	7,508	0	0	1,929,071				
Sangamon	6	241,422	262,434	287,518	454,855	535,187	16,754	0	1,798,170	255.64	28.48	6.11	7,034
	5	314,194	1,564,041	1,141,701	37,867	0	0	0	3,057,803	509.59	68.18	5.21	6,000
Totals		555,616	1,826,475	1,429,219	492,722	535,187	16,754	0	4,855,973				
Schuyler	6	0	0	0	0	0	0	0	0	0.0	0.0		
	5	0	51,667	0	0	0	0	0	51,667	8.97	0.0	5.00	5,760
Totals		0	51,667	0	0	0	0	0	51,667				
Shelby	6	395,635	174,030	259,691	655,871	458,343	7,361	0	1,950,931	285.42	2.40	5.93	6,835
	5	114,371	21,082	0	0	0	0	0	135,453	28.48	0.58	4.13	4,756
Totals		510,006	195,112	259,691	655,871	458,343	7,361	0	2,086,384				
Stark	6	440,549	0	0	0	0	0	0	440,549	95.61	3.28	4.00	4,608
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		440,549	0	0	0	0	0	0	440,549				
Tazewell	6	0	0	0	0	0	0	0	0	0.0	0.0		
	5	234,446	138,002	0	0	0	0	0	372,448	74.84	7.40	4.32	4,977
Totals		234,446	138,002	0	0	0	0	0	372,448				
Vermilion	6	299,802	405,461	311,510	52,871	92	0	0	1,069,736	187.09	36.83	4.96	5,718
	5	0	0	0	0	0	0	0	0	0.0	0.0		
Totals		299,802	405,461	311,510	52,871	92	0	0	1,069,736				
Wabash	6	239,003	19,256	1,866	0	0	0	0	260,125	55.48	0.0	4.07	4,689
	5	199,304	113,251	156,803	94,336	98,427	11,923	2,419	676,463	109.34	0.0	5.37	6,187
Totals		438,307	132,507	158,669	94,336	98,427	11,923	2,419	936,588				

Washington	6	69,942	139,937	750,112	1,577,617	972,870	188,570	94,856	3,793,904	[illegible]	0.00	6.92	[illegible]
	5	13,948	0	0	0	0	0	0	13,948	3.03	0.0	4.00	4,608
Totals		83,890	139,937	750,112	1,577,617	972,870	188,570	94,856	3,807,852				
Wayne	6	908,937	332,348	97,386	17,050	2,599	0	0	1,358,320	271.44	0.0	4.34	5,004
	5	955,769	136,910	36,716	0	0	0	0	1,129,395	236.50	0.0	4.15	4,776
Totals		1,864,706	469,258	134,102	17,050	2,599	0	0	2,487,715				
White	6	783,839	301,534	141,587	12,177	3,871	0	0	1,243,008	244.87	0.80	4.41	5,076
	5	659,803	408,607	326,317	252,175	9,401	0	0	1,656,303	293.63	0.0	4.90	5,641
Totals		1,443,642	710,141	467,904	264,352	13,272	0	0	2,899,311				
Williamson	6	23,395	110,063	233,194	130,795	54,525	19,803	0	571,775	81.97	106.04	6.06	6,976
	5	838,513	68,602	0	0	0	0	0	907,115	193.88	18.52	4.06	4,679
Totals		861,908	178,665	233,194	130,795	54,525	19,803	0	1,478,890				
Seam totals													
Coal seam	6	13,300,102	12,657,243	12,290,311	11,586,777	7,831,170	1,018,906	256,668	58,941,177	9,269.00	927.18	5.52	6,359
Coal seam	5	20,261,331	11,321,567	5,572,030	806,097	249,413	24,485	9,677	38,244,600	7,298.91	331.18	4.55	5,240
State totals		33,561,433	23,978,810	17,862,341	12,392,874	8,080,583	1,043,391	266,345	97,185,777				

* *Does not include coal underlying oil and gas fields.*

† *Refers only to seams more than 42 inches thick.*

‡ *Mined-out area reflects all areas mined regardless of seam thickness.*

TABLE B—DEMONSTRATED COAL RESERVES* OF THE UNITED STATES AND ESTIMATED ENERGY POTENTIALS BY STATE

(Compiled by Ramesh Malhotra, Illinois State Geological Survey Mineral Economics Group)

	Demonstrated coal reserves base‡ (million short tons)				*Coal heat content* (Btu)			
	Method of mining							
State	Underground	Surface	Total	Percentage of U. S. total	Range** (Btu/lb)	Av. heat content value used (Btu/lb)	Potential energy available (Trillion Btu)	Percenta of U. S. total
Alabama	1,798	1,184	2,982	0.68	12,620–14,160	13,410	79,977	0.90
Alaska	4,246	7,399	11,645	2.68	9,000–14,500	10,000	232,900	2.61
Arizona		350	350	0.08	N. A.	N. A.	N. A.	N. A.
Arkansas	402	263	665	0.15	11,910–14,600	13,255	17,629	0.20
Colorado	14,000	870	14,870	3.43	9,060–13,680	11,370	338,143	3.79
Georgia	1		1	0.00				
Illinois	53,442	12,223	65,665	15.14	9,700–12,700	11,260	1,478,776	16.59
Indiana	8,949	1,674	10,623	2.45	10,900–11,590	11,510	244,541	2.74
Iowa	2,885		2,885	0.67	N. A.	N. A.		
Kansas		1,388	1,388	0.32	10,500–13,300	11,900	33,034	0.37
Kentucky, East	9,467	3,450	12,917	2.98	12,300–14,200	13,110	338,684	3.80
Kentucky, West	8,720	3,904	12,624	2.90	11,930–12,940	12,140	306,511	3.43
Maryland	902	146	1,048	0.24	12,890–14,480	13,680	28,673	0.32
Michigan	118	1	119	0.03	N. A.	11,570	2,753	0.03
Missouri	6,074	3,414	9,488	2.18	10,312–13,485	11,000	208,736	2.34
Montana	65,165	42,562	107,727	24.82	5,675–9,500	7,587	1,634,649	18.34
New Mexico	2,136	2,258	4,394	1.01	10,150–13,500	11,825	103,918	1.16
North Carolina	31	†	31	0.01				
North Dakota		16,003	16,003	3.69	7,004	7,004	224,170	2.51
Ohio	17,423	3,654	21,077	4.85	11,006–12,919	12,070	508,726	5.70
Oklahoma	860	434	1,294	0.29	13,500–13,755	13,627	35,267	0.39
Oregon	1	†	1	0.00				
Pennsylvania	29,819	1,181	31,000	7.15	12,580–14,490	13,270	822,740	9.23
South Dakota		428	428	0.10				
Tennessee	667	320	987	0.22	10,980–14,380	13,250	26,155	0.29
Texas		3,272	3,272	0.75	7,800–11,500	10,600	69,366	0.77
Utah	3,780	262	4,042	0.93	10,400–13,220	11,200	90,540	1.01
Virginia	2,971	679	3,650	0.84	11,170–15,000	13,530	98,769	1.11
Washington	1,446	508	1,954	0.45	up to 15,000	13,000	50,804	0.57
West Virginia	34,378	5,212	39,590	9.13	10,200–15,600	13,540	1,072,097	12.02
Wyoming	27,554	23,674	51,228	11.80	7,640–13,110	10,375	1,062,981	11.92
Total	297,235	136,713	433,948	100	5,675–15,600	10,272	8,915,028	100

* *Demonstrated coal reserves are defined by the U. S. Bureau of Mines as in-place coals, 28 inches or more thick in bituminous coal or anthracite and 60 inches or more thick in sub-bituminous coal or lignite. Maximum depth is 1,000 feet for all except lignite, for which only strippable beds less than 120 feet deep are considered.*

† *Less than 1 million short tons.*

Sources of data: (‡) *U. S. Bureau of Mines, 1974;* (**) *Library of Congress Congressional Research Service, 1973, Science Policy Research Division.*

TABLE C—REMAINING COAL RESERVES IN ILLINOIS, BY COUNTY AND COAL SEAM, JANUARY 1975*

(in millions of tons)

County	Danville (No. 7)	Herrin (No. 6)	Harrisburg-Springfield (No. 5)	Summum (No. 4)	Colchester (No. 2)	De Koven	Davis	Rock Island (No. 1)	Misc. coals	Total	Percent strippable	Total strippable coal
Adams					624.556					624.556	99.1	618.690
Bond		2,451.950		299.867	2.092				2.472	2,756.381	0.0	0.0
Brown					385.672					385.672	100.0	385.672
Bureau	424.110	645.286			1,221.789					2,291.185	19.6	448.260
Calhoun					15.015					15.015	100.0	15.015
Cass			104.933		452.957					557.890	43.9	244.903
Champaign		181.884								181.884	0.0	0.0
Christian	61.454	3,429.950	1,336.120						86.660	4,914.180	0.0	0.0
Clark	316.655	11.848	511.149						379.885	1,219.537	0.0	0.0
Clay		916.819	702.311							1,619.130	0.0	0.0
Clinton		3,233.922		552.248						3,786.170	0.0	0.0
Coles	312.112	153.769	44.046							509.927	0.0	0.0
Crawford	211.152	571.817	929.166						736.948	2,449.083	1.8	43.162
Cumberland		162.249	171.260						3.845	337.354	0.7	2.385
De Witt			173.619							173.619	0.0	0.0
Douglas		698.279	11.011						10.063	719.353	0.0	0.0
Edgar	950.564	721.363	441.259						878.903	2,992.089	0.0	0.0
Edwards		684.316	1,031.565							1,715.881	0.0	0.0
Effingham		622.072	1,164.351						1.248	1,787.671	0.1	1.248
Fayette	296.023	2,773.953	159.646						0.595	3,231.617	0.1	1.995
Franklin		1,932.538	1,977.950			362.147	507.878		64.989	4,845.492	0.1	2.949
Fulton	58.882	242.309	630.310	5.448	1,293.242			5.266		2,235.457	86.2	1,926.658
Gallatin		1,311.641	1,298.862			650.600	856.675		6.836	4,124.613	5.6	229.238
Greene		97.274		25.199	583.351					705.824	84.7	597.777
Grundy				32.912	843.040					875.952	39.3	344.214
Hamilton		2,611.967	2,192.953			3.557	5.336			4,813.809	0.0	0.0
Hancock					54.299					54.299	54.9	29.829
Hardin						1.177	2.421			3.598	0.0	0.0
Henderson					53.111					53.111	100.0	53.111
Henry	58.878	260.289			668.819			16.374		1,004.359	56.1	563.665
Jackson		204.036	216.742						265.346	686.124	54.1	371.489
Jasper		1,861.661	1,415.200							3,276.861	0.0	0.0
Jefferson		2,699.818	2,442.508						23.842	5,166.164	0.5	23.842
Jersey	10.482	71.256			197.747					279.485	78.9	220.461
Kankakee				35.845	83.903					119.748	19.8	23.657

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TABLE C—*Continued*

County	Danville (No. 7)	Herrin (No. 6)	Harrisburg-Springfield (No. 5)	Summum (No. 4)	Colchester (No. 2)	De Koven	Davis	Rock Island (No. 1)	Misc. coals	Total	Percent strippable	Total strippable coal
Knox	2.523	214.221	643.471		803.634			57.526		1,721.375	89.2	1,535.181
La Salle	489.782	217.016			1,430.898					2,137.696	13.1	280.404
Lawrence	223.427	1,186.698	985.024						424.738	2,950.929	0.0	0.0
Livingston	257.569	354.555		16.060	2,351.608					2,979.792	1.7	49.226
Logan			2,588.664							2,588.664	0.0	0.0
McDonough					584.320					584.320	100.0	584.320
McLean	603.370		316.337		296.406					1,216.113	0.0	0.0
Macon		162.928	1,689.960							1,852.888	0.0	0.0
Macoupin	15.510	3,932.400		75.354	1,657.211		126.363		697.334	6,504.160	4.2	275.605
Madison		1,917.752			660.361		4.675		8.015	2,590.802	23.8	615.350
Marion		1,216.002	748.495							1,964.497	0.0	0.0
Marshall	337.381	9.749			858.033					1,205.163	9.6	116.023
Mason			23.271							23.271	0.0	0.0
Menard			1,598.550		23.775					1,622.325	33.7	545.943
Mercer					17.859			53.959		71.818	96.1	69.024
Monroe		6.726								6.726	100.0	6.726
Montgomery	24.972	3,721.394		609.721	558.844		133.353		513.415	5,561.691	0.0	0.0
Morgan		621.585	18.021	22.531	1,322.351					1,984.488	41.7	827.534
Moultrie		355.524								355.524	0.0	0.0
Peoria	282.537	1,044.423	1,189.911		429.868					2,946.739	72.6	2,138.070
Perry		2,107.053	400.565							2,507.618	35.3	885.104
Piatt			10.698							10.698	0.0	0.0
Pike					144.401					144.401	100.0	144.401
Putnam	197.035	78.676			467.893					743.604	0.0	0.0
Randolph		424.499	171.947							596.396	64.4	384.323
Richland		1,191.832	932.509						5.192	2,129.533	0.2	5.192
Rock Island								62.133		62.133	67.6	42.000
St. Clair		2,278.792		621.565						2,900.357	36.2	1,048.720
Saline	78.422	1,327.901	917.924	6.885	7.768	691.250	1,133.060		3.178	4,166.387	11.8	491.469
Sangamon		2,139.717	3,324.204		280.804				4.086	5,748.801	7.3	418.366
Schuyler			113.394		597.672					711.066	100.0	711.066
Scott		6.120			249.499					255.619	88.7	226.609
Shelby	125.267	1,183.577	304.861						90.945	1,704.650	5.0	84.570
Stark	57.703	427.678			25.781					511.162	100.0	511.124
Tazewell	4.152	69.686	129.019		202.528					405.385	37.0	150.005

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TABLE C–*Concluded*

County	Danville (No. 7)	Herrin (No. 6)	Harrisburg-Springfield (No. 5)	Summum (No. 4)	Colchester (No. 2)	De Koven	Davis	Rock Island (No. 1)	Misc. coals	Total	Percent strippable	Total strippable coal
Vermilion	1,677.961	698.070							44.521	2,420.552	8.7	209.980‡
Wabash		575.908	880.457						158.473	1,614.838	9.8	158.473
Warren			0.807		415.271			38.928		455.006	88.5	402.593
Washington		3,461.731		650.598						4,112.328	0.0	0.0
Wayne		2,349.795	2,275.301							4,625.094	0.0	0.0
White		2,364.131	2,248.345			13.823	17.204			4,643.496	0.0	0.0
Will					9.460					9.460	100.0	9.460
Williamson	57.022	634.708	910.562	2.648		742.119	615.894		188.386	3,151.337	17.9	564.069
Woodford	38.560		144.770		990.850					1,174.180	0.0	0.0
Total	7,173.473	64,832.960	39,347.823	3,075.118	20,866.625	2,464.672	3,402.857	1,225.322	4,599.915	146,988.765	13.4	19,637.689
Additions to reserves†		3,558.602	11,098.763							14,657.365		
Revised total	7,173.473	68,391.562	50,446.586	3,075.118	20,866.625	2,464.672	3,402,857	1,225.322	4,599.915	161,646.130	12.1	19,637.689

* *Totals include coal seams 28 inches or more thick in all cases of reliability, as defined in this report and previous Illinois State Geological Survey publications. Strippable coals include coals 18 inches or more thick under 150 feet or less overburden.*

† *These additions reflect new reserves of coal identified in the remapping of the coal seams in this study.*

‡ *Not based on detailed study.*

TABLE D–POTENTIAL RESERVOIRS IN ILLINOIS

County	Reservoir site no.	Pool area (acre)	Storage (ac-ft)	Storage (million gal)	Watershed area (sq mi)	Net yield* (mgd)
Adams	12	1,980	42,900	14,000	34.7	7.3
Adams	13	3,250	69,300	22,600	206.0	22.2
Adams	26	25,885	906,010	295,178	346.9	91.4
Adams	26A	15,288	433,156	141,122	346.9	76.4
Adams	27	3,813	63,558	20,707	103.5	15.0
Alexander	2A	1,363	38,164	12,434	25.8	12.4
Bond	8	12,000	204,000	66,463	471.7	60.9
Bond	11	6,850	134,000	43,657	297.0	38.8
Boone	3	1,040	15,600	5,082	69.0	12.2
Brown	14A	1,344	53,760	17,515	30.6	8.2
Brown	15	6,100	164,700	53,700	324.0	48.6
Brown	18	1,324	35,307	11,503	37.2	6.9
Bureau	2	1,060	12,370	4,020	98.0	7.2
Bureau	3	973	17,800	5,800	85.4	10.0
Bureau	4	1,730	34,600	11,260	186.6	17.2
Carroll	1	2,138	57,000	18,600	35.1	11.7
Carroll	2	2,310	50,100	16,300	57.0	13.3
Carroll	6	9,646	212,212	69,139	157.8	41.3
Christian	13	2.195	29,267	9,535	83.1	6.8
Christian	14	6,466	64,659	21,066	247.3	17.6
Christian	15	3,814	50,853	16,568	97.5	10.9
Clark	2	1,410	28,200	9,185	48.0	6.3
Clark	9	1,690	30,980	10,090	80.0	7.2
Clark	9A	2,320	50,267	16,377	80.0	14.0
Clark	18	2,403	36,045	11,743	85.0	11.5
Clark	19	1,138	24,657	8,033	25.1	6.6
Clay	1	12,000	160,000	52,130	472.0	46.2
Clay	3	2,100	28,700	9,350	50.0	6.8
Clay	11	13,500	230,800	75,195	661.0	68.5
Clinton	10	3,060	21,420	6,979	131.0	9.3
Clinton	13	4,054	40,540	13,208	140.1	7.1
Coles	1	3,100	24,800	8,080	303.0	15.5
Coles	2A	1,059	21,180	6,900	30.0	6.5
Coles	8	3,700	71,500	23,290	112.7	18.4
Coles	14	6,760	65,450	21,324	915.0	47.5
Coles	14A	18,500	470,957	153,438	915.0	177.1
Coles	15	2,207	20,599	6,711	526.5	14.8
Coles	16	3,668	40,348	13,145	566.9	21.4
Coles	17	5,443	68,945	22,462	695.1	32.2
Crawford	15	2,408	40,117	13,070	34.9	8.8
Crawford	18	3,229	41,977	13,676	30.3	8.0
Cumberland	1A	2,059	37,748	12,298	32.0	8.9
Cumberland	5	2,470	54,340	17,700	32.0	9.5
Cumberland	8A	1,612	26,867	8,753	62.0	8.2
Cumberland	12A	1,922	32,033	10,436	55.0	9.1
Cumberland	19	2,922	38,960	12,693	134.8	13.4
Cumberland	19A	6,466	129,320	42,132	134.8	34.8
Cumberland	20	2,142	34,272	11,166	58.3	9.6
Cumberland	20A	3,764	85,317	27,796	58.3	18.3
De Witt	3	2,682	5,000	16,300	118.4	18.0

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TABLE D—*Continued*

County	Reservoir site no.	Pool area (acre)	Storage (ac-ft)	Storage (million gal)	Watershed area (sq mi)	Net yield* (mgd)
De Witt	8	5,000	76,750	25,005	298.3	62.5
De Witt	9	2,677	31,232	10,175	227.4	16.3
Edgar	2	2,000	58,000	15,640	145.0	13.8
Effingham	9	10,616	212,320	69,174	218.8	48.1
Effingham	10	9,372	124,960	40,712	554.1	41.2
Fayette	9	5,100	136,000	44,309	91.1	26.6
Fayette	10	4,341	86,820	28,286	119.0	21.9
Fayette	11	1,930	32,167	10,480	47.7	8.7
Fayette	12	3,394	67,880	22,115	44.4	14.6
Fayette	13	4,732	94,640	30,834	84.8	18.2
Fayette	14	3,947	78,940	25,718	93.9	19.1
Fayette	15	4,160	109,000	35,512	84.0	20.4
Fayette	16	3,900	86,000	28,019	81.0	17.8
Fayette	16A	5,929	138,343	45,072	80.2	24.3
Fayette	16B	2,998	49,967	16,279	80.2	11.7
Franklin	4A	2,014	26,853	8,749	20.8	7.2
Fulton	5	1,100	29,300	9,500	32.1	8.4
Fulton	13	2,110	35,200	11,500	91.2	13.9
Fulton	14A	1,753	35,060	11,423	50.8	12.5
Fulton	31	1,024	27,307	8,897	27.8	7.9
Fulton	32	8,911	237,627	77,419	292.9	78.0
Fulton	35	1,825	24,333	7,928	55.4	9.2
Fulton	35A	4,356	101,639	33,114	55.4	18.9
Fulton	36	11,746	234,920	76,437	1,846.5	185.6
Fulton	36A	22,926	840,620	273,873	1,846.5	372.4
Gallatin	1	5,920	39,467	12,860	417.0	22.2
Gallatin	1A	7,007	46,713	15,219	417.0	20.3
Gallatin	1B	27,510	275,100	89,644	417.0	78.0
Gallatin	1C	14,404	144,040	46,938	417.0	50.0
Gallatin	5	2,250	42,500	13,849	16.6	6.7
Greene	16	4,344	75,296	24,531	146.3	13.8
Greene	26	7,808	140,544	45,789	278.0	34.9
Greene	17	15,858	343,590	111,942	367.3	48.5
Hancock	11	1,920	30,100	9,800	61.2	8.7
Hancock	12	7,040	129,000	42,000	285.0	41.0
Hancock	32	3,521	49,294	16,060	86.2	11.4
Hancock	33	2,726	49,977	16,282	82.0	14.6
Hancock	34	1,629	21,720	7,076	84.2	8.3
Hancock	36	1,236	26,780	8,725	37.3	7.6
Hardin	1A	1,361	32,664	10,642	10.4	6.3
Hardin	5	1,830	36,600	11,926	39.0	12.5
Hardin	5A	2,711	63,257	20,609	36.9	15.9
Henry	16	2,010	20,100	6,549	57.3	10.2
Jasper	8	1,750	26,200	8,536	46.9	6.5
Jasper	11	2,345	31,267	10,187	59.3	8.7
Jasper	12	2,810	37,467	12,207	75.7	9.2
Jefferson	1A	5,795	115,900	37,760	42.0	15.0
Jefferson	1B	3,904	65,067	21,199	42.0	11.6
Jefferson	1C	2,403	32,040	10,439	42.0	7.8
Jefferson	2	4,224	77,400	25,234	47.9	18.0

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TABLE D—*Continued*

County	Reservoir site no.	Pool area (acre)	Storage (ac-ft)	Storage (million gal)	Watershed area (sq mi)	Net yield* (mgd)
Jefferson	3	3,846	66,664	21,723	48.0	17.5
Jefferson	8	6,655	133,100	43,364	46.8	19.7
Jefferson	8A	2,537	33,827	11,021	46.8	9.1
Jefferson	9	5,279	114,378	37,264	38.4	17.0
Jefferson	9A	2,215	33,225	10,825	38.4	9.2
Jefferson	10	9,739	194,780	63,459	50.2	22.1
Jefferson	10A	5,338	71,173	23,188	50.2	15.0
Jefferson	10B	3,767	50,227	16,364	50.2	12.3
Jersey	7	2,580	68,800	22,410	83.0	11.2
Jersey	9	1,980	49,500	16,130	40.8	6.5
Jo Daviess	2	662	17,700	5,800	20.6	6.0
Jo Daviess	5	810	26,400	8,600	17.1	6.1
Jo Daviess	9	877	18,400	6,000	25.2	7.2
Jo Daviess	10	667	17,787	5,795	20.4	6.4
Johnson	2	2,900	20,300	6,615	40.0	7.6
Johnson	2A	3,773	50,307	16,390	37.9	15.9
Johnson	6A	1,981	33,017	10,757	21.7	9.2
Johnson	11	8,883	118,440	38,587	113.3	35.7
Johnson	12	1,402	46,733	15,226	269.9	31.6
Knox	4A	1,873	31,217	10,170	26.1	7.2
Knox	20	1,697	22,627	7,372	46.2	8.1
Knox	21	2,207	44,140	14,381	36.3	9.9
Knox	22	2,201	29,347	9,561	67.9	10.7
Knox	23	1,324	26,480	8,627	24.9	7.0
Knox	24	1,435	35,875	11,688	28.5	8.4
Knox	26	1,069	23,162	7,546	25.6	6.7
La Salle	5	698	20,900	6,800	123.0	7.7
La Salle	11	763	13,995	4,560	241.3	9.6
Livingston	6	2,805	37,400	12,185	1,071.1	24.3
Logan	7	2,001	21,344	6,954	316.0	21.5
Logan	7A	3,678	51,492	16,776	316.0	36.3
McDonough	13	1,170	21,060	6,900	41.1	6.2
McDonough	14	2,148	35,800	11,664	67.9	11.3
McDonough	15	1,344	29,120	9,487	60.6	10.1
McHenry	2	1,280	8,960	2,919	21.6	7.3
McLean	10	1,677	39,130	12,748	37.4	8.8
Macoupin	27	2,871	38,279	12,471	210.8	13.4
Macoupin	27A	10,833	216,660	70,588	210.8	28.2
Macoupin	29	11,859	213,462	69,546	400.0	53.8
Madison	15A	4,026	45,628	14,866	112.2	12.8
Madison	17	4,578	122,080	39,774	103.5	19.5
Madison	19	4,820	86,760	28,266	109.4	17.6
Madison	20	3,206	41,678	13,579	85.9	11.0
Marion	13	3,200	53,300	17,360	96.1	14.3
Marion	14	10.550	179,400	58,449	210.0	46.0
Marion	15	3,017	36,204	11,795	90.6	9.6
Marshall	14	941	21,957	7,154	33.4	6.1
Marshall	15	3,256	113,960	37,128	127.1	27.2
Menard	1	1,382	31,315	10,200	38.8	7.1
Menard	1A	2,296	52,808	17,205	51.6	11.0

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TABLE D—*Continued*

County	Reservoir site no.	Pool area (acre)	Storage (ac-ft)	Storage (million gal)	Watershed area (sq mi)	Net yield* (mgd)
Menard	1B	2,751	73,360	38,573	51.3	12.1
Mercer	1	804	16,100	5,200	31.6	6.7
Mercer	2	2,496	49,900	16,300	54.0	15.3
Mercer	11	145	2,420	788	3.7	6.0
Mercer	12	1,158	15,800	5,100	35.8	6.8
Mercer	13	5,000	116,700	38,000	92.5	29.2
Monroe	4A	2,562	51,240	16,694	36.1	9.8
Monroe	8	2,363	75,616	24,636	56.2	14.4
Monroe	9	5,941	79,213	25,808	164.8	23.8
Montgomery	10	9,859	177,460	57,816	326.5	48.5
Montgomery	10A	17,555	403,765	131,547	331.6	61.3
Montgomery	14	2,571	35,994	11,727	62.6	8.3
Morgan	6	2,125	37,525	12,200	104.4	9.0
Morgan	20	5,619	112,380	36,613	159.6	19.0
Peoria	3	1,062	27,612	9,000	42.7	7.8
Peoria	8	1,312	27,985	9,100	34.4	7.8
Peoria	20	3,155	90,422	29,500	61.3	19.2
Perry	2	2,080	28,400	9,254	48.0	8.5
Perry	12	4,855	64,733	21,090	45.9	13.1
Perry	13	9,055	120,733	39,335	99.0	25.4
Perry	14	5,729	76,387	24,887	109.9	21.5
Perry	15	6,511	86,813	28,284	107.2	20.5
Pike	2	4,950	132,000	43,000	92.0	21.6
Pike	10	1,410	28,200	9,200	39.1	6.9
Pike	22	2,574	85,800	27,954	59.0	15.6
Pike	23	3,034	96,077	31,302	39.1	18.4
Pike	24	4,150	166,000	54,083	50.2	26.4
Pike	26	1,903	66,605	21,700	27.8	13.3
Pike	26A	1,196	33,887	11,040	27.8	8.7
Pike	28	1,854	58,710	19,128	27.7	12.3
Pike	30	2,511	50,220	16,362	79.0	11.3
Pope	2	2,830	75,467	24,590	37.0	18.4
Pope	3	900	26,000	11,730	24.0	8.8
Pope	3A	1,260	50,400	16,420	23.8	12.1
Pope	4	780	18,200	5,330	39.0	7.0
Pope	6	3,600	96,000	31,281	81.0	29.1
Pope	8	1,886	50,293	16,385	42.0	12.4
Pope	9	3,375	101,250	32,987	54.8	26.1
Pope	10	2,155	71,833	23,403	54.4	21.0
Putnam	1	1,100	25,700	8,400	53.9	9.7
Putnam	2	570	16,200	5,300	35.0	6.0
Putnam	3	698	18,600	6,100	35.4	6.4
Randolph	1	2,650	35,333	11,513	84.0	10.8
Randolph	1A	10,032	200,640	65,369	83.2	33.4
Randolph	2	1,460	17,520	5,709	90.0	6.5
Randolph	14	1,500	21,000	6,843	71.0	6.7
Randolph	20	4,802	80,033	26,075	81.8	19.3
Randolph	21	5,211	104,220	33,955	84.7	22.9
Randolph	21A	3,231	53,850	17,544	84.7	16.6
Richland	9	3,474	34,742	11,318	59.4	9.5

(Continued on next page)

TABLE D—*Continued*

County	Reservoir site no.	Pool area (acre)	Storage (ac-ft)	Storage (million gal)	Watershed area (sq mi)	Net yield* (mgd)
Richland	11	27,794	370,591	120,738	23.9	12.5
Rock Island	1	1,037	15,500	5,100	46.6	6.2
Rock Island	4	1,320	21,600	7,000	60.4	8.5
St. Clair	12	2,204	29,387	9,574	41.9	7.8
St. Clair	13	3,665	36,650	11,941	81.8	10.7
Saline	4	3,300	121,000	39,428	26.9	10.7
Saline	4A	4,546	212,147	69,117	28.5	10.8
Saline	4B	1,902	50,720	16,525	28.5	8.7
Sangamon	9B	3,837	66,508	21,668	84.5	9.9
Sangamon	21	12,500	208,300	67,864	869.0	65.8
Sangamon	22	2,088	38,280	12,472	93.9	7.3
Sangamon	23A	2,475	37,950	12,364	38.5	6.6
Sangamon	24A	1,932	25,760	8,393	54.6	6.9
Sangamon	24B	4,131	68,850	22,431	54.6	11.5
Sangamon	25	2,105	29,470	9,601	52.9	7.6
Schuyler	8	1,856	52,580	17,100	52.0	12.5
Schuyler	21	4,440	78,440	25,600	87.0	18.9
Schuyler	25	1,559	33,778	11,005	62.0	10.5
Schuyler	26	2,883	86,490	28,178	33.4	10.2
Schuyler	26A	1,706	39,807	12,969	33.4	8.3
Schuyler	27	2,324	46,480	15,143	161.8	19.4
Schuyler	28	1,912	28,680	9,344	94.5	11.5
Schuyler	28A	3,491	75,638	24,643	94.5	21.1
Schuyler	30	1,500	37,500	12,218	27.3	7.3
Scott	5	2,029	39,221	12,800	63.8	7.1
Scott	11	2,628	42,048	13,699	127.1	9.5
Scott	14	2,815	51,608	16,814	125.2	12.2
Shelby	8	3,246	43,280	14,101	114.2	11.6
Shelby	9	2,216	22,160	7,220	102.7	6.1
Shelby	10	4,080	89,760	29,244	85.1	19.2
Stark	6	2,770	53,500	17,400	64.4	15.6
Stark	7	5,070	92,950	30,283	194.3	37.6
Stark	8	5,041	84,017	27,373	130.6	28.9
Stephenson	2	640	6,400	2,100	27.4	6.0
Stephenson	5	448	5,200	1,700	31.0	6.3
Stephenson	7	1,427	19,000	6,200	49.7	12.1
Tazewell	8A	1,507	32,652	10,638	33.6	8.0
Tazewell	11	1,206	24,120	7,858	42.9	6.9
Tazewell	12	2,079	41,580	13,547	49.0	10.8
Union	10	1,830	39,650	12,920	38.6	15.0
Union	10A	2,138	35,633	11,609	35.0	12.5
Union	14A	1,013	16,883	5,500	19.3	6.5
Union	15	1,200	12,000	3,910	24.3	6.1
Union	15A	2,277	30,360	9,891	22.4	10.3
Union	16	3,310	88,267	28,762	48.6	25.1
Union	16A	2,536	50,720	16,525	47.7	19.2
Vermilion	2	2,500	42,500	13,900	500.0	27.4
Vermilion	13	3,800	81,067	26,412	434.4	45.6
Vermilion	14	1,345	20,175	6,573	175.1	15.7
Warren	9	1,146	19,482	6,300	31.5	6.0

(Concluded on next page)

TABLE D—*Concluded*

County	Reservoir site no.	Pool area (acre)	Storage (ac-ft)	Storage (million gal)	Watershed area (sq mi)	Net yield* (mgd)
Warren	11	954	13,356	4,400	102.3	8.6
Washington	11	2,696	35,000	11,403	52.2	8.3
Washington	11A	3,351	44,680	14,557	51.8	10.7
Washington	13	5,529	71,877	23,418	71.0	16.0
Wayne	5	6,204	62,040	20,213	160.7	19.9
Whiteside	7	1,304	17,387	5,665	142.5	22.7
Will	5	580	5,025	1,636	40.0	6.1
Williamson	8A	3,456	103,680	33,779	32.9	13.3
Williamson	8C	1,808	42,187	13,749	32.9	8.5
Williamson	11	5,357	71,667	23,349	58.4	19.8
Woodford	3A	1,593	53,114	17,304	28.8	8.5
Woodford	11	1,574	34,090	11,100	71.8	8.1
Woodford	11A	3,741	99,772	32,505	1.8	19.9
Woodford	13	3,251	55,270	18,000	130.9	11.9
Woodford	13A	8,401	196,021	63,863	130.9	35.3
Woodford	20	3,940	63,032	20,536	340.5	17.2

* *Based on using half the reservoir capacity during a 40-year drouth.*

TABLE E–QUALITY OF SURFACE WATER FROM THE MAIN WATERSHEDS OF ILLINOIS

(Highest concentration or highest measured value in mg/l for indicated percentage of samples analyzed)

Watershed	Sampling station		Alkalinity			Hardness			Total dissolved minerals			Nitrate			Turbidity			Temperature (°F)			Sampling period	Number of samples	Watershed area (sq mi)
	Location	Number	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%			
WISCONSIN DRIFTLESS REGION																							
Apple River	Hanover	14	195	285	315	240	325	345	285	345	370	2	5.5	8.5	7	2	0.4	32	54	75.5	1957-1961	46	244
ROCK RIVER HILLS																							
Rock River	Como	23	175	240	270	225	290	330	280	340	390	2	6.5	12	7	3	0.6	32	56	78	1957-1961	59	8,700
WHEATON MORAINAL REGION																							
Fox River	Algonquin	2	200	230	280	275	315	380	340	385	450	3	6	11	5	2	0.5	33	55	77	1957-1961	60	1,364
Du Page River	Troy	6	160	240	285	330	400	470	420	530	630	2.5	10.5	17	10	3	0.2	33	56	79	1945-1950	51	325
GREEN RIVER LOWLAND																							
Green River	Geneseo	26	165	235	255	255	350	385	315	405	445	0.5	4	12	20	4	0.5	32	60	74	1945-1950	53	958
BLOOMINGTON RIDGED PLAIN–NORTH																							
Fox River	Dayton	30	185	230	290	275	320	375	350	400	480	3.5	7.5	13.5	7	3	0.7	32.5	60	78	1956-1961	60	2,570
KANKAKEE PLAIN																							
Vermilion River	Pontiac	38	170	220	255	265	350	455	340	415	530	2	9	28	25	4	0.7	33	56	80.5	1957-1961	51	568
Vermilion River	Lowell	39	155	220	260	250	355	460	310	445	685	3	11	28	10	2	0.4	32	57.5	78.5	1957-1961	54	1,230
Iroquois River	Iroquois	36	95	200	225	140	305	355	220	375	420	2	10	17	10	4	0.1	32	49.5	78	1950-1956	51	682
Kankakee River	Wilmington	32	145	190	210	255	315	345	330	390	435	1.5	6	19	20	2	0.4	32.5	56	78	1956-1961	52	5,250
GALESBURG PLAIN																							
La Moine River	Colmar	73	80	205	250	105	255	285	190	320	380	1.5	3.5	10	100	4	0.8	32	57	74	1957-1961	50	655
La Moine River	Ripley	72	70	165	220	110	225	290	150	270	350	1.5	5	10.5	90	10	2	33	57	76	1945-1950	49	1,310
Spoon River	London Mills	49	110	230	270	175	315	375	210	385	495	0.5	6.5	13.5	55	7	2	32	55	80	1945-1950	47	1,070
Spoon River	London Mills	49	160	260	310	230	350	440	315	440	625	1.5	6.5	14.5	45	4	0.7	32.5	59	78	1957-1961	48	1,070
INTERSECTIONAL																							
Illinois River	Meredosia	104	125	155	180	195	245	300	295	360	415	4.5	17	27.5	25	8	4	33	56	81	1955-1960	60	25,300
Illinois River	Peoria	102	120	150	180	200	250	300	255	330	400	5.5	9.5	16	100	31	10	34	59	80	1945-1949	48	
Illinois River	Peoria	102	135	160	180	225	260	320	330	385	450	3.4	10	18	70	37	13	32	54	81	1957-1961	50	
LINCOLN HILLS																							
Hadley Creek	Barry	75	80	160	190	110	180	215	165	230	260	0.5	2	6	25	2	0.5	34.5	61	85	1956-1961	59	40.6
SPRINGFIELD PLAIN																							
Embarras River	Ste. Marie	84	145	210	270	200	280	310	255	330	385	1	5.5	16	25	3	0.5	33	59.5	79	1956-1961	60	1,513
Kaskaskia River	Vandalia	106	105	210	265	130	275	315	170	345	445	1	3.5	12.5	25	3	0.5	34	54	81	1950-1956	50	1,980
Kaskaskia River	New Athens	81	40	125	215	75	185	305	130	285	435	2	5	10	50	10	2	34	59	78	1945-1950	55	5,220
Kaskaskia River	New Athens	81	50	135	215	80	210	300	150	315	500	1.5	4.5	9	55	9	2	34	57	78	1957-1961	48	
Sangamon River	Oakford	71	155	235	265	205	305	330	265	380	430	1.5	5	13.5	25	2	0.5	34	60.5	75.5	1957-1961	60	5,120
Little Wabash River	Wilcox	86	50	105	190	85	175	275	165	285	435	0.5	2	5.5	20	3	0.9	33.5	53	80	1950-1955	60	1,130
Indian Creek	Wanda	79	125	210	250	175	305	355	245	385	440	1.5	4	8	30	5	1	34	55	77	1945-1950	58	37
Macoupin Creek	Kane	78	75	200	250	125	265	345	160	330	440	1	4	8	70	7	1	34	56	78.5	1945-1950	60	875
BLOOMINGTON RIDGED PLAIN–SOUTH																							
Kaskaskia River	Shelbyville	105	80	200	255	125	320	625	170	405	1080	0.5	8	23.5	10	2	0.2	33	60	78	1956-1961	60	1,030
Sangamon River	Monticello	60	165	235	300	225	320	350	270	375	485	2.5	8.5	27	8	2	0.3	33	51.5	74.5	1956-1961	60	550
Salt Creek	Rowell	65	140	260	315	180	305	335	230	355	460	3	7	17.5	20	2	0.3	33.5	54	76	1950-1956	59	334
Mackinaw River	Green Valley	103	150	250	320	195	320	350	260	350	390	1.5	6.5	18.5	25	2	0.5	35	50	80	1950-1956	60	1,100
Vermilion River	Catlin	101	170	230	300	225	290	340	285	390	560	4	13.5	20.5	7	1	0.4	34	52	78	1950-1956	60	959

TABLE E–*Concluded*

Watershed	Sampling station		Alkalinity			Hardness			Total dissolved minerals			Nitrate			Turbidity			Temperature (°F)			Sampling period	Number of samples	Watershed area (sq mi)
	Location	Number	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%			
MT. VERNON HILLS																							
Skillet Fork	Wayne City	88	15	60	105	60	170	260	115	295	435	0.5	2	3.5	30	6	2	33	56.5	76.5	1945-1950	54	475
Skillet Fork	Wayne City	88	25	55	115	60	135	295	125	260	530	1	2.5	4.5	25	5	2	33	60	78	1957-1961	51	475
Big Muddy River	Plumfield	92	10	30	70	60	145	335	110	295	675	1	2.5	6.5	20	10	2	35	57	79.5	1945-1950	58	753
Big Muddy River	Murphysboro	107	25	50	100	100	200	440	205	425	795	1.5	3.5	5	30	5	2	36	58.5	77	1956-1961	55	2,170
Crab Orchard Lake	Wolf Creek	109	20	40	60	100	120	140	175	210	240				5	3	1	37	58	82.5	1951-1956	55	
Crab Orchard Lake	Station 5	108	20	35	50	85	100	120	150	165	220	0.5	1	2.5	5	1	0.5	37	56.5	83	1951-1956	55	
Little Wabash River	Carmi	89	30	75	150	65	150	240	140	280	470	1.5	3	5.5	35	5	2	33.5	61	78	1957-1961	50	3,111
Saline River	Junction	90	20	75	165	65	265	655	120	460	1010	1.5	2.5	3.5	20	5	1	35	60	79	1945-1950	41	1,040
SHAWNEE HILLS																							
Cache River	Forman	96	30	55	95	40	70	110	75	120	165	1	2	3.5	40	6	2	34	59	77	1957-1961	60	243
INTERSECTIONAL																							
Wabash River	Riverton, Ind.	117	110	180	220	165	260	325	225	340	405	3.5	12	26	45	9	2	38	59.5	82	1955-1960	60	13,100
Wabash River	Mt. Carmel	116	115	180	225	165	250	310	215	305	395	2	6	10.5	25	3	1				1950-1956	56	28,600
Ohio River	Metropolis	115	45	70	90	85	120	150	125	170	215	1.5	3.5	6	9	3	0.5	34	59	77	1950-1956	52	203,000
Ohio River	Cairo	114	60	75	95	100	135	165	150	205	255	1.5	4	6.5	10	4	0.9	34.5	66	83	1958-1961	42	
Mississippi River	Keokuk, Iowa	110	100	135	160	125	170	190	165	200	230	0.5	3	6.5	30	3	0.7	32.5	54	81	1950-1955	56	119,000
Mississippi River	East St. Louis	111	120	150	180	155	205	245	210	280	300	2.5	6	11	60	8	1	34	62	82.5	1958-1961	41	
Mississippi River	Chester	112	110	135	190	160	200	250	230	290	360	1.5	7	18	75	20	6	33	56.5	82	1955-1960	60	712,600
Mississippi River	Thebes	113	115	150	175	160	200	240	235	300	370	2	4.5	7.5	75	20	5				1951-1956	59	717,200

APPENDIX 2

METHODS USED TO COMPILE ESTIMATES OF COAL RESERVES

METHODS USED TO COMPILE ESTIMATES OF COAL RESERVES

Jay P. Hoeflinger and Lawrence E. Bengal

INTRODUCTION

The basic data for this report were drawn from the Illinois Geological Survey's comprehensive compilation of the estimated coal reserves of the state, made in 1952 (Cady and others, 1952). For that study, the Illinois coal field was divided into 33 areas (text figure 18). For each area a base map on a scale of approximately 1 inch to the mile was constructed by combining eight 15-minute quadrangle maps in two horizontal rows of four. Drill holes, mined-out areas, coal outcrops, and the thickness of each coal seam were plotted on the base maps. The reserves were then planimetered by hand to obtain area measurements for each increment of thickness and reliability used in the classification scheme shown in text table 3. The results were tabulated on punched cards by county, township, coal seam, coal seam thickness, and reliability of data. Tabulating machines (Parker, 1946) were then used to compute and tally the total tonnages of coal.

For the present study, two computer programs, the Coal Resource System and GEOMAPS, were developed at the Illinois Geological Survey for computing areas and volumes of coal within each of the reserve categories. The heart of the two systems is ILLIMAP, which also was developed at the Illinois Geological Survey in 1970 by Swann and his co-workers. ILLIMAP draws base maps of all or any part of Illinois to any desired scale. Its effectiveness lies in its data base, which consists of coordinates obtained from U.S. Geological Survey 7.5-minute quadrangle maps on which every section corner in the state is expressed in rectangular coordinates of the Lambert coordinate system (DuMontelle et al., 1968). This is a significant feature because it provides a basis for accurate location of datum points. ILLIMAP also includes all of the county and state boundaries and Indian treaty lines in Illinois.

COAL RESOURCE SYSTEM

Data Preparation

At the beginning of this study of coal reserves, the maps showing the thickness of the Herrin (No. 6) and Harrisburg–Springfield (No. 5) Coals that were made for the 1952 study were updated to include all the information that had been collected since 1952. To simplify the updating, transparent Mylar base maps were prepared on the same scale as the 1952 base maps, and new drill-hole information, boundaries of areas mined out since 1952, and information from studies of specific areas made in recent years were plotted on the Mylar bases. The Mylar maps were then placed ov the 1952 base maps so that information from both could b used in mapping the extent of the Herrin and Harrisburg Springfield Coals in Illinois and in interpreting the thic ness of the coals.

After the interpreted maps of the coal seams had bee prepared, the operation was fully computerized. The firs step was the entry of the updated information and the r interpreted coal-thickness lines. An Autotrol digitizer a the State Water Survey was used for this process. To b handled by the digitizer, our basic map unit had to be re duced from the eight quadrangles used in the 1952 study t two quadrangles. Each map unit was digitized and given specific code to identify its location within the state.

Because of the type of data available, interpreted coa isopachs and other hand-drawn lines representing coal fea tures, rather than actual point data, were digitized. Thi information was then recorded on a magnetic tape for entry into the computer.

Program Procedure

The digitizer-tape loading program reads successive records from the tape and records the Lambert coordinates of the map corners for use by ILLIMAP and other routines in the system. Every point is assigned a two-digit decimal value, which identifies that point. Because interpreted data instead of actual point data were digitized, the two-digit decimal value represents an isoline on the map. The coordinates of every point on an isoline and the value for each are stored in the coordinate files. The coordinate files include a feature-coordinate file and a coal-coordinate file. The coal-coordinate file holds only coal isopachs, while the feature-coordinate file holds lines representing all other coal features affecting the calculation of reserves (fig. A). Both types of files are then read by the Coal Resource System and are used for calculations of area and volume.

The Coal Resource System program accesses the coal-coordinate and feature-coordinate files for a particular map. In several steps the program builds a numerical surface that represents the coal surface portrayed on the hand-drawn coal-reserve work maps. This numerical surface is then used by the program to calculate the coal reserves for that particular map and to categorize the reserves into the classes that are necessary for further processing. By interfacing this coal surface with ILLIMAP, the coal reserves can be calculated by township, county, and seam thickness, as is demonstrated in table A (Appendix 1). These estimates of coal reserves are then stored in a statis-

COAL–COORDINATE FILE
(Coal thickness lines, inches)

42
54
66
78
90
102
114
126

FEATURE–COORDINATE FILE
(Boundaries of areas excluded from reserves)

Outcrop of coal
Thin or absent coal
Split coal
Sandstone channel
Mined–out areas
Oil pools
150–foot depth line
Limit of classified coal
Insufficient data

Figure A. The two types of coordinate files used to form the computer-generated mathematical surfaces for coal reserve estimates.

file, where they can be accessed by several display and ection programs.

GEOMAPS

GEOMAPS is the mapping and surface graphics system eloped at the Illinois State Geological Survey. The sys- i is composed of the ILLIMAP program, the FORMA- ON program, and IBM's STAMPEDE (IBM Corporation, 58). STAMPEDE is a series of programs for forming l manipulating numerical surfaces. It can approximate ays of datum points by a uniform grid, generate trend faces of the first through the eighth order, evaluate poly- nial representations of surfaces, and perform normal ntouring on a plotter or printer.

The basic ILLIMAP program was modified to convey e-map parameters to the STAMPEDE program and the al Resource System. These modifications allow an in- idual program to interrogate the ILLIMAP coordinate e in order to orient itself to the geographical area under ıdy. ILLIMAP also conveys the scale, map limits, angle orientation, plotter limits, and scale-conversion factors. e Geological Survey's routine called FORMATION was added to facilitate plotting the coal-feature lines from digitized point data.

MAPPING TECHNIQUES

An important feature of the Coal Resource System is its ability to plot information. Digitized lines for coal thickness and coal features are stored in coordinate files that can be accessed by the system's plotting routines, which are based on GEOMAPS. GEOMAPS can draw on a plotter unlimited combinations of digitized lines to any desired scale for any part of Illinois.

With format-free control cards the user can (1) call for particular lines by name; (2) cause symbols to be drawn on any of these lines at a predetermined frequency; (3) cause characters to be entered in the townships of any or all counties to represent tons per square mile, total tons of coal, total area of coal, weighted average thickness, or total square miles of mined-out area; and (4) cause lines to be drawn in different colors.

In this study the reserve estimates for each coal were factored into tons of coal in the average square mile for each township that contained Herrin or Harrisburg–Springfield Coals 42 or more inches thick. Six categories were set up for tons of coal in the average square mile, beginning with 4 to 5 million tons and progressing in million-ton increments to 9 or more million tons. Each category was assigned an alphabetic symbol, with A the smallest and F the largest. These symbols were plotted on a base map (fig. B) (Smith and Miller, 1975). The lettered map was translated into colors that represented the coal reserves in individual townships, as shown on plates 1 and 2, which accompany this report.

CONCLUSIONS

A unique feature of the system devised for this study was the use of interpreted coal-thickness data as computer input in place of actual point data. This approach had the advantage of saving much time and expense in the making of a point-oriented data base.

The key factor in the development of the Coal Resource System was the availability of the computer-based mapping system, ILLIMAP. ILLIMAP was used not only to plot the final maps, but also to locate input maps in relation to each other and to provide tabulations of coal reserves by geographical area. A coal reserves mapping system with the capabilities outlined here could probably not be developed without a mapping system similar to ILLIMAP.

The relative error of the computerized approach was compared to that of a manual approach by planimetering

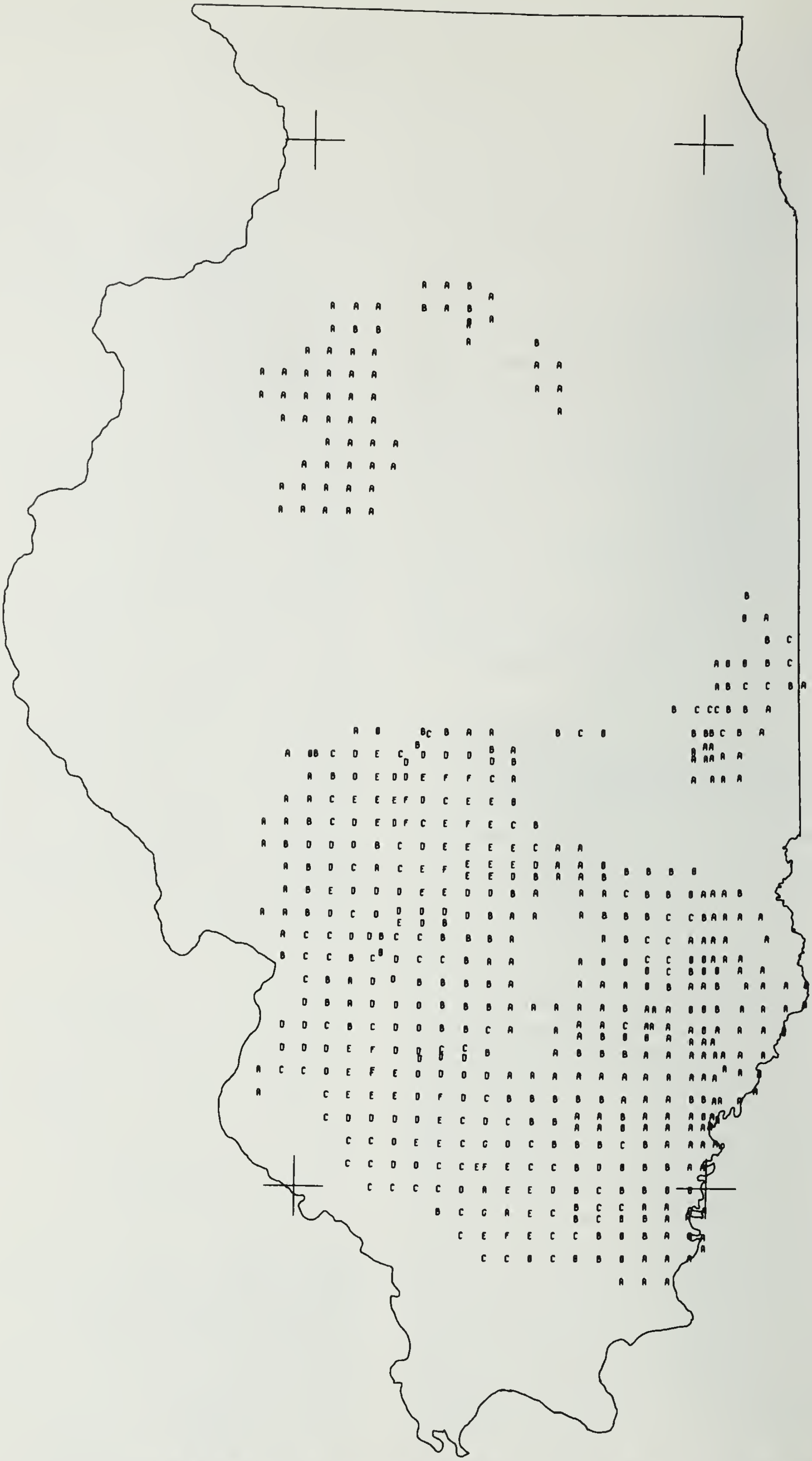

Figure B. A computer-generated map of letter symbols that represent colors to be used for a choropleth map of the average tons of coal in place per square mile for each township in which the Herrin Coal has been mapped. A similar map was made for the Harrisburg-Springfield Coal. The values range from letter A (4 million tons per square mile) to the letter F (9 or more million tons per square mile). The crosses are registration marks.

eral test townships. In general, the difference between two approaches was 5 percent or less. The errors in s computerized approach are inherent in any uniform-d, numerical-surface technique; they arise from the size of the grid used to represent the coal surface. This error becomes insignificant as the grid interval approaches zero; however, the execution time, and therefore the cost factor, increases rapidly as the grid interval decreases.

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Urbana, Illinois 61801

FOX CHAIN OF LAKES INVESTIGATION AND WATER QUALITY MANAGEMENT PLAN

V. KOTHANDARAMAN, RALPH L. EVANS, NANI G. BHOWMIK, JOHN B. STALL,
DAVID L. GROSS, JERRY A. LINEBACK, and GARY B. DREHER

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1977

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STATE WATER SURVEY
STATE GEOLOGICAL SURVEY

COOPERATIVE RESOURCES REPORT 5

URBANA, ILLINOIS
1977

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Fox Chain of Lakes Investigation and Water Quality Management Plan

by V. Kothandaraman, Ralph L. Evans, Nani G. Bhowmik,
John B. Stall, David L. Gross, Jerry A. Lineback, and Gary B. Dreher

INTRODUCTION

The Fox Chain of Lakes consists of nine major internally connected lakes located in Lake and McHenry Counties in northern Illinois. The main inflow into the lake system is the Fox River. Other tributaries of importance are the Sequoit, Nippersink, and Squaw Creeks, and Lily Lake Drain. The drainage area of the Fox River at Johnsburg, immediately downstream of the Fox Chain of Lakes, is 1184 square miles. Approximately 75 percent of the drainage area lies in Wisconsin. *[For locations, see figure 13, page 34.]*

The surface water levels of the system are maintained by a dam at McHenry. At normal pool elevation, the water surface area of the lake system is about 6850 acres. The shoreline extends 48 miles and there is an additional 30 miles of dredged channel shoreline to accommodate demands for lake frontage property.

Cultural Development and Land Use

The lands surrounding the Fox Chain of Lakes were being cleared of forests by 1840. The cleared land was converted to row-crop agriculture. From that original agricultural base, the shores of the Chain were steadily converted to residential and recreational uses. The interconnected bodies of water, natural shoreline, picturesque beauty, and proximity to Chicago have combined to make the Chain a popular area for swimming, boating, water skiing, fishing, and resort development.

The shores of these lakes were first dotted by summer homes but those have long been converted to year-round occupancy. All of the shore naturally suitable (and much of it not suitable) for construction of homes, restaurants, marinas, and other recreational facilities has been developed.

Artificial channels have been dredged to accommodate demands for lake frontage property. The recreational value of the lakes is a major economic influence in the area. Regional planners report there is no area in the surrounding six counties with greater potential for meeting the varied recreational needs of people in the region. However, the full potential of the Chain area is not being realized because of the eutrophic conditions existing in the system's waters.

The Problem

The lakes and their associated shorelands constitute a valuable natural resource that is showing the effects of use and abuse by more and more people. A population with growing leisure time, greater affluence, and increased mobility has imposed spiraling demands on the recreational resources of the region. The Illinois Department of Conservation (1964) in a special report indicated that 4000 boats existed in the lake waters in 1915. Today, Lake County officials estimate that 35,000 boats are harbored on the Chain and that over 2 million gallons of gasoline are used annually by boaters.

Nuisance algal blooms have been a source of recorded complaints on the Chain for at least the past 35 years. Such protests expressed apprehension regarding the curtailment of bathing, boating, water skiing, fishing, lowering of property values, cancellation of resort trade, and impairment of the picturesque beauty of the Chain. Luxuriant and prolonged algal blooms, periodic fish kills, and offensive odors have been reported during many investigations (Illinois Department of Conservation, 1964; Lake County Health Department, 1962; and U.S. Public Health Service, 1963; *see References in Part 3*).

With the exception of a 14-month study by the Lake County Health Department, all earlier investigations have been limited in scope and have been predicated upon complaints. An occasional investigation has been undertaken with a specific objective in mind such as a fish population count (Illinois Department of Conservation, 1964) or bacterial density enumeration (Lake County Health Department, 1962).

The eutrophic conditions existing annually in the middle and lower Fox River in Illinois are related to the Fox Chain of Lakes. The Chain, being upstream, contributes massive concentrations of algae to the river waters, impairing the recreational and aesthetic enjoyment sought by the residents of the valley. The benefits of needed waste treatment facilities along the course of the Fox River are not likely to be realized so long as its headwaters remain grossly eutrophic.

Clearly, a thorough evaluation was needed of the processes governing algal growth in order to develop technically sound and economically feasible management plans for controlling the problems of excessive fertilization of the Chain of Lakes. The successful application of a strategy for restoring desirable water quality within the Chain would serve two purposes. It would offer relief consistent with the needs of sportsmen, swimmers, boaters, and sightseers as well as persons depending upon the active use of the Chain for their livelihood; and it would permit the subsequent development of a water quality management plan for the Fox River in Illinois which is greatly influenced by the lake system.

Objectives and Scope

Primary objective of this investigation was to gain an understanding of the Fox Chain of Lakes' hydrological, physical, chemical, and biological characteristics. This knowledge would be used to develop short-term and long-term strategies leading to restoration and preservation of desirable water quality in the Chain. Efforts were directed to updating hydrologic maps for the lake system, determining the water circulation patterns, defining the extent of thermal and dissolved oxygen stratifications in the lakes, documenting the temporal and spatial variations in chemical and biological water quality, investigating the geology and geochemistry of the lake bottoms, identifying the critical elements responsible for the profuse algal growth in the lake system, and developing a nutrient budget for the lake system.

The State Water Survey in cooperation with the State Geological Survey began the 18-month detailed investigation of the Fox Chain of Lakes in October 1974. The investigation was encouraged and funded by the Illinois Institute for Environmental Quality. The U.S. Geological Survey collected the interflow data between lakes and developed rating curves for three newly installed gaging stations in the Chain of Lakes region. Water samples from the tributaries and outflow from the system were collected by the Lake County Health Department. The Illinois Department of Conservation assisted in collecting rainwater samples.

Report Plan

This report is a cooperative project of the Illinois State Water Survey and State Geological Survey. Part 1, prepared by the Geological Survey, discusses the geologic history and character of bottom sediments. Parts 2 and 3 were prepared by the Water Survey. Part 2 presents the hydraulic and hydrologic conditions of the Chain. Part 3 discusses the water quality and sources of nutrients and the living organisms. Part 3 also evaluates remedial measures found effective in other locations and proposes a reliable water management program.

Acknowledgments

This investigation, sponsored and financially supported by the Illinois Institute of Environmental Quality, was conducted under the general supervision and guidance of Dr. William C. Ackermann, Chief of the Illinois State Water Survey. Many Water Survey personnel contributed to the final preparation of this report. John W. Brother, Jr., and William Motherway, Jr., prepared the illustrations for Parts 2 and 3. J. Loreena Ivens and Patricia A. Motherway edited the manuscript. Suzi O'Connor typed the camera copy.

The authors of Part 1 are indebted to the following members of the Illinois State Geological Survey staff for their performance of chemical analyses: John D. Steele and Jim F. Ashby, atomic absorption spectrometry analyses; Eleanor F. Hopke, optical emission spectography; Joyce Kennedy Frost, instrumental neutron activation analysis; Larry R. Camp, radiochemical neutron activation analysis; David B. Heck and Mark A. Seifrid, inorganic carbon and boron tests; Lawrence Kohlenberger and Renee M. Gracon, total carbon and nitrogen analysis; John K. Kuhn and Leonard R. Henderson, X-ray fluorescence spectrometry; and Dennis D. Coleman and Chao-Li Lui, radiocarbon dating. Grain-size analyses of sediments were supervised by Susan K. Friesen. Statistical analyses were performed by John A. Schleicher. Figures in Part 1 were prepared by members of the Geological Survey staff.

James King, Illinois State Museum, did the palynology and contributed to the understanding of the sedimentation rates. Jerry T. Wickham assisted with all field work and data compilation. The Illinois Division of Water Resources furnished a boat from which to collect samples and allowed the use of their warehouse and dock facility at McHenry Lock and Dam where Lockmaster Frank Novak was most helpful.

The following Water Survey Hydraulic and Hydrology personnel participated in the Part 2 investigation under the supervision of John B. Stall, Head of the Hydrology Section. Ji-Ang Song and Jeffery C. Elledge assisted in analysis of the data. David J. Kisser, Gary L. Ahlberg, and Steven Glenn carried out the field work and collected the circulation data. Wilbur Debolt, Jr., assisted in the installation of the wind-set.

All horizontal and vertical control surveying was performed by the Engineers Surveying and Calculating Service of Mount Prospect through a subcontract. This firm also collected all of the sounding information. The Illinois Division of Water Resources supplied all long-term stage records in the Chain and flow records at McHenry Lock and Dam. The U.S. Geological Survey (Madison, Wisconsin, office) supplied flow records for the Fox River at Wilmot, Wisconsin. The Ranger's office at Chain of Lakes State Park furnished a boat whenever needed, and stored instruments for our investigators. All property owners in the Chain of Lakes area were helpful, cooperative, and pleasant to those collecting data for the study.

The following personnel, under the supervision of Ralph L. Evans, Head of the Water Quality Section, participated in various phases of the Part 3 investigations, namely, sample collection, analyses, data reduction and evaluation, and report writing: Gary Benker, Davis B. Beuscher, Thomas A. Butts, David L. Hullinger, Melbern E. Jannett, Shundar Lin, Meri Phillips, Dorothy L. Richey, Donald Roseboom, Donald H. Schnepper, Wun-Cheng Wang, and Jack W. Williams, Jr. Rebecca Phillips typed the original manuscript. Dr. J. C. Neill, Water Survey statistician, performed the statistical analyses and Calcomp plotting.

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Part 1. Geology and Sediment Geochemistry of the Lakes

GEOLOGIC HISTORY

The geologic history of the Fox Chain of Lakes essentially began with the melting of the last of the great continental glaciers from Illinois. That last episode of glaciation, the Woodfordian substage of the Wisconsinan stage, had begun when ice flowed southwestward from the Lake Michigan Basin 23,000 years ago. The time has been documented by a radiocarbon date (I-2783) on the organic Robein Silt which was penetrated by a boring made 20 miles south of the lakes. The Woodfordian glaciers flowed southward, covering the northeastern quarter of Illinois, and reached their maximum extent at Peoria and Shelbyville 20,000 years ago. For the next 6000 years the glacial front retreated northward, a withdrawal interrupted by many minor readvances.

The final episode of Woodfordian glaciation occurred about 14,000 years ago, when two minor sublobes of the glacier met along what is now the western side of the Fox Chain of Lakes. Ice flowed into McHenry County from the north, bringing from the northern Silurian dolomite area the sandy yellow-brown till now named the Haeger Till Member of the Wedron Formation (Willman and Frye, 1970). Meltwater from the ice deposited great thicknesses of sand and gravel outwash. At the same time the other lobe of glacial ice flowed westward or southwestward into Lake County from the Lake Michigan Basin and deposited the olive-gray clayey till now referred to as the Wadsworth Till Member of the Wedron Formation (Willman and Frye, 1970). That till was derived from erosion of Devonian shales in the Lake Michigan Basin.

The two minor sublobes met along what is now the Lake–McHenry County line just west of the Chain of Lakes. The line is marked by a prominent escarpment separating the uplands (elevation 268 meters) (880 feet) of McHenry County from the lowlands (elevation 229 meters) (750 feet) surrounding the lakes. The line also separates the coarse-grained surficial till, sand, and gravel materials of McHenry County from the clayey till, silts, clays, and peats of the lake basins and regions to the east in Lake County. The glacial lobe coming from the north melted first, possibly 13,000 years ago, allowing the Fox River to begin flowing southward as an ice marginal stream on the western front of the lobe coming from the east. The eastern lobe then melted quickly, leaving a hummocky kame-and-kettle topography formed by the deposition of vast quantities of glacial debris. Buried in that debris were many large blocks of ice that, as they melted, left depressions filled with meltwater. It was the melting of these buried ice blocks that formed the Chain of Lakes in the random pattern that we see today. A detailed map of the surficial deposits in Lake County was published in Larsen (1973), and a similar map of the surficial deposits in McHenry County may be found in Hackett and McComas (1969).

The original depths of the lakes are not known but they probably were not much deeper than the 12 meters (40 feet) maximum observed today. Just after the lakes were formed, sedimentation rates were very high because surrounding slopes slumped into more stable positions and the Fox River brought in muddy glacial meltwater. After the glacial ice melted and the climate began to warm, sedimentation rates slowed, but they have risen again in the past 150 years as human activities in the surrounding watershed have increased.

Volo Bog, 4 kilometers (2.4 miles) south of Pistakee Lake, was another lake formed at the same time and by the same processes as the Chain, but it is now almost completely filled by muck, peat, and marl. McComas et al. (1972) described in considerable detail the formation and history of that bog, and most of their discussion applies equally well to the Chain. The Fox Chain of Lakes differs from the bog principally in the amount of filling that has taken place.

It is no accident that the lakes along the Fox River (Grass, Nippersink, and northern Pistakee Lakes) are shallow today and that those away from the river channel (Marie, Channel, and Catherine Lakes) are relatively deep. Where the river's course is through deep lakes, the rate of flow drops and much of the river's sediment load is deposited. Thus the sedimentation rates are high in the first deep-water areas encountered as the river flows through the Chain. Natural infilling of the lakes undoubtedly progressed from north to south and is largely complete in Grass, Nippersink, and northern Pistakee Lakes.

In 1907, the construction of the first dam across the Fox River at McHenry increased water levels in the Chain and also reduced water velocities, causing an increase in sedimentation rates. Sedimentation also increases after each episode of dredging. Grass Lake is an exception because it has an erosional bottom today. No significant quantity of recent sediment has been deposited in Grass Lake, and its shore is eroding slightly. Possibly the slight rise of water level caused by the dam allowed wave action to scour the bottom of this the shallowest lake in the Chain.

The area surrounding the Chain of Lakes is included in four major soil associations which are described in detail in the excellent soil reports for Lake and McHenry Counties by Paşchke and Alexander (1970) and Ray and Wascher (1965). The area west of Channel, Marie, and Fox Lakes and the areas surrounding Grass, Nippersink, and Pistakee Lakes are included in the Marsh-Fox-Boyer soil association. It is a marshy area, level to rolling, with well to moderately well drained soils that are moderately deep, lie over sand and gravel, and have rapid to moderate permeability.

The areas east of Lakes Catherine and Channel, those southwest of Lake Marie, and those west of Bluff, Spring, and Petite Lakes are in the Nappanee–Montgomery soil association. This area is made up of level to moderately sloping soils that are somewhat poorly drained and deep soils that have slow permeability, are level to depressional, and poorly to very poorly drained.

The east side of Bluff, Spring, Petite, and Fox Lakes is in the Morley-Markham-Haughton soil association, which includes deep soils of moderately slow permeability that are gently sloping to steep and well to moderately well drained. Level to depressional, very dark colored, very poorly drained organic soils also are in that association. The south side of Fox Lake is included in the Zurich-Grays-Wauconda soil association, which consists of nearly level to moderately steep, well drained to somewhat poorly drained, deep soils that have moderate permeability.

TYPES OF SEDIMENT

Silt, sand, peat, marl, muck, glacial-lacustrine clay, and glacial till were found in 80 cores and 25 surface grab samples from the bottom of the Fox River Chain of Lakes (figure 1). Cores were taken with a Benthos open-tube gravity corer (Gross et al., 1970). Each core was collected in a plastic tube that had an inside diameter of 6.7 centimeters (2.6 inches). Most cores were from 80 to 120 centimeters (2.6 to 3.9 feet) long.

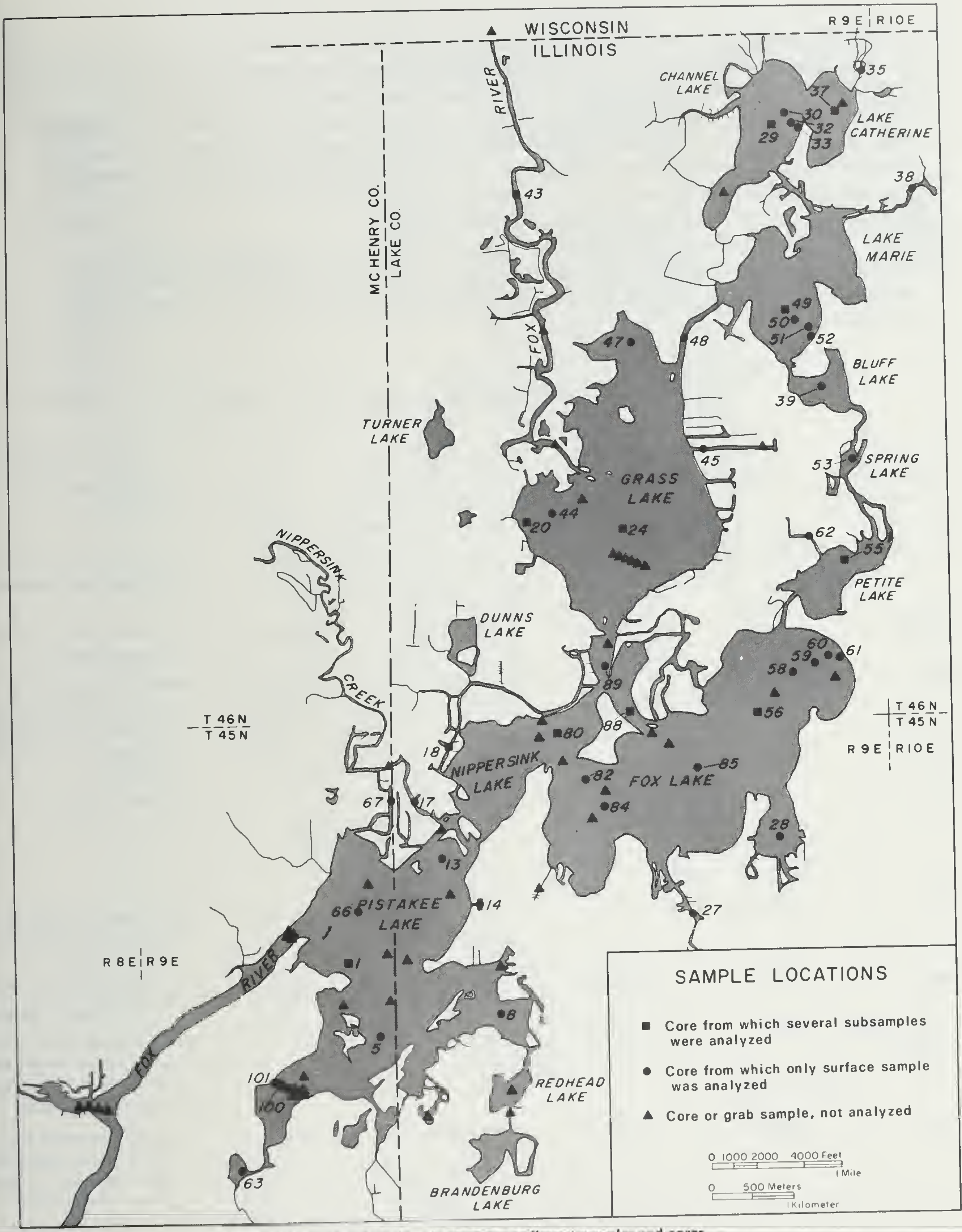

Figure 1. Sampling locations for bottom sediment samples and cores

The coring was done from a pontoon boat operated by the Division of Water Resources (Illinois Department of Transportation) at McHenry Dam. Some cores were extruded from their tubes and subsampled on the boat; others were returned to the Illinois State Geological Survey laboratories in Urbana for subsampling. The depth of penetration of the cores was not sufficient to permit examination of the entire postglacial sediment sequence in the lakes, and, therefore, little can be said about the deeper stratigraphic record. However, the cores and bottom samples taken furnish a relatively detailed picture of the types of sediment now accumulating in the Chain of Lakes system.

Nine different types of sediment can be identified in the top meter (3.3 feet) of sediment (table 1) in the Chain of Lakes, and those units have been simplified to the seven sediments shown in figure 2. Each sediment type represents a particular environment within the lake-river system.

Table 1. Types of Sediment in the Fox River Chain of Lakes

Type	*Major component*	*Minor component*	*Type of organic debris*	*Color*	*Type of environment*
Silt with sand and/or shells	Silt	Sand and/or shells	Coarse debris from marsh vegetation and algal remains	Black to brownish black	Open lake, shallow < 2 meter of water
Peaty silt	Silt	Plant fragments	Mostly peaty debris from marsh vegetation	Black	Open lake, shallow < 2 meter of water near marshes
Algal silt	Silt	Algal fragments	Algal filaments	Black	Open lake, deeper than 2 meters of water
Marl	Calcarenite and shells		Little	Light gray	Open lake, generally 2-4 meters deep in narrow zon between nearshore silty sediments and deep water algal silts
Muck	Silt	Clay	Fine to coarse debris from marshes, trees, other channel-side vegetation, and septic tank outfalls		Dredged channels
Peat	Plant debris		Coarse marsh vegetation	Brownish black	Peat marshes and places where lakes have transgressed older marshes
Sand	Sand	Shells, silt	Some coarse plant debris	Dark gray	Channel of Fox River and other tributary channels
Glaciolacustrine clay	Clay	Sand, silt	Very little debris	Gray	Areas of steep slope and other places where recent sediments have not accumulate or have been eroded
Till	Clay	Sand, silt	Very little debris	Gray	Areas of steep slope and other places where recent sediments have not accumulate or have been eroded

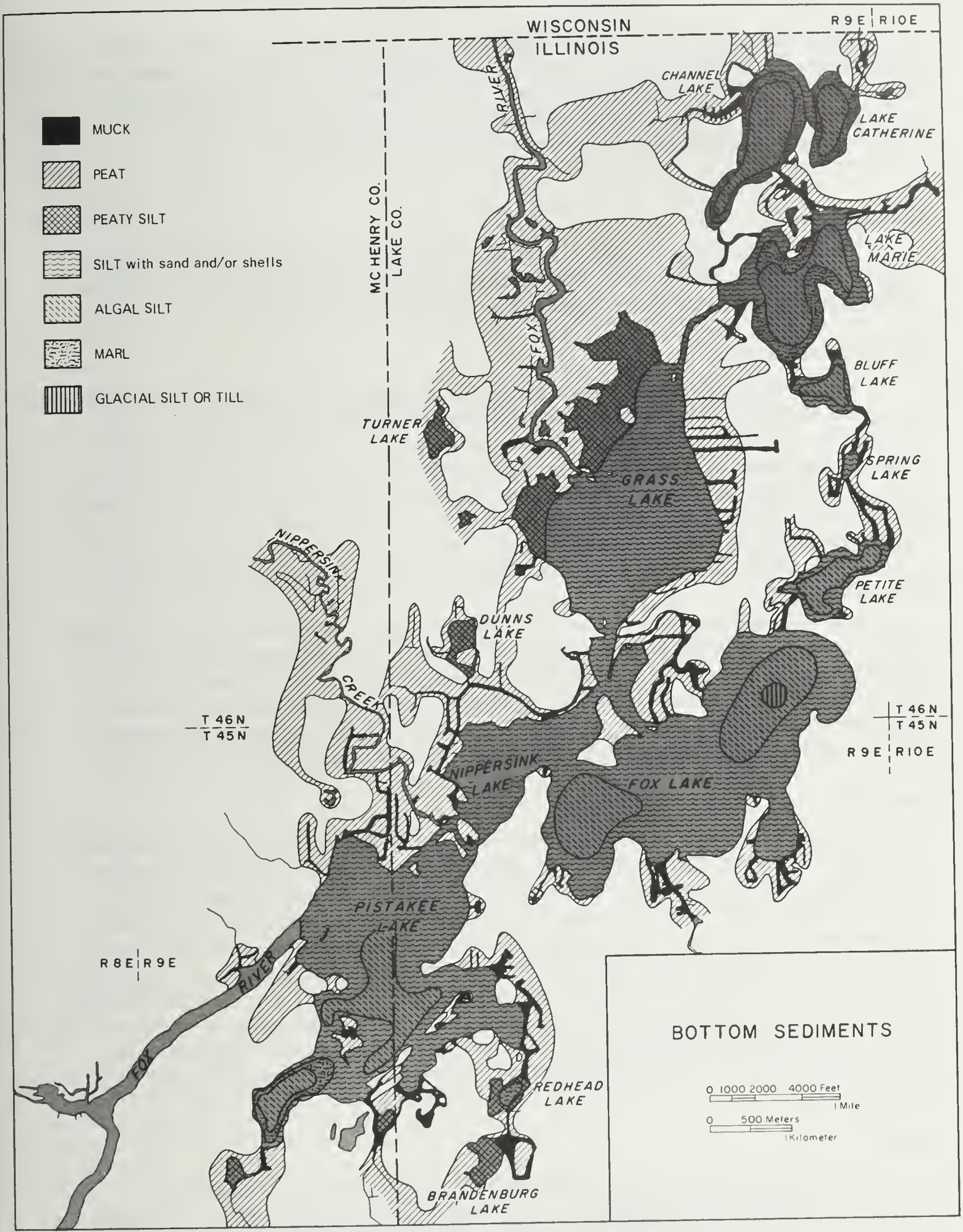

Figure 2. Distribution of various types of bottom sediments

Sixty-three selected sediment samples were analyzed chemically for 27 major and minor components (tables 2 and 3). Grain-size determinations were made on 61 samples. Pollen from three cores was examined to determine the percentage of *Ambrosia* (ragweed) pollen present. The geochemistry of each sediment type is distinctive and is related both to the environment of deposition as well as to the sediment components.

Lake Sediments

Black silt containing abundant peat-like plant debris has the widest distribution on the floors of the nine lakes studied. Three subtypes of black silt were identified on the basis of the kinds of plant debris they contain and on their sand or shell content.

Silt with Sand and/or Shells

Silt containing shells and/or sand is the most common type of sediment now accumulating in the lakes (figure 2). This type of sediment is generally found in water less than 2 meters (6.6 feet) deep (figure 3) in the larger channels connecting the lakes, in the shallow lakes, and in the near-shore areas of deep lakes. This sediment averages 71 percent silt (table 2). The sand content ranges from 0 to 15 percent and is highest in Nippersink Lake and in the portions of Grass and Pistakee Lakes that are most affected by the through-flow of Fox River water. Sand is also found in near-shore sediments where the shores are steep. Shells (mostly gastropods and a few clams) are abundant in shallow water away from the main channels between the lakes.

The sediment contains an average of 5 percent organic carbon. Coarse and fine plant debris is present in all samples. This type of silt has the most heterogeneous origin of all the lake sediments. It is a mixture of quartz silt and sand, and clay minerals carried into the lakes by creeks, rivers, and shore erosion; algal debris; plant debris derived from marshes and shore vegetation; and calcium carbonate from calcareous algae and whole and broken shells of gastropods and clams that lived on the lake bottom or on vegetation in the lakes.

Peaty Silt

A second sub-variety of black silt sediment is peaty silt, which differs from the sandy and shelly silt in having considerably fewer shells and proportionately more peaty organic matter (up to 26.5 percent organic carbon) (table 2). Samples of peaty silt were collected from areas into which the lakes have recently expanded at the expense of the surrounding peat bogs and marshes. Grass Lake is a good example. A comparison of present day maps of Grass Lake with those made over 50 years ago shows considerable portions of marsh now covered with 0.5 to 1 meter (1.6 to 3.3 feet) of water. The installation of McHenry Dam on the Fox River, which resulted in higher water levels and increased natural wave erosion of the shore, along with the activities of motor boats, has been responsible for the extension of the lake. Most of the added organic material in the sediment is coarse plant debris from near-by marshes.

Algal Silt

The third type of black silt is present in the deeper water areas of all the lakes except Nippersink and Grass (figure 2). It is generally found in water deeper than 2 meters (6.6 feet), but may accumulate in shallow water if located sufficiently far from shore, as

Table 2. Geochemistry of the Surface Sediments in the Fox Chain of Lakes Region

Core	Inorganic carbon	Organic carbon	Total carbon	N	P_2O_5	S	SiO_2	Al_2O_3	K_2O	CaO	MgO	Fe_2O_3	TiO_2	MnO	Sand	Silt	Clay
								(percent)									
Silt with sand and/or shells																	
1	8.20	4.12	12.32	.46	.22	.69	18.16	2.84	.60	36.36	3.00	1.99	.19	.047	48.1	51.7	0.2
5	10.00	2.30	12.30	.19	.11	.66	6.79	1.20	.21	46.80	0.26	1.14	.04	.028			
8	7.46	7.01	14.47	.54	.20	.64	15.08	2.41	.44	33.10	2.25	1.51	.13	.020			
13	6.76	3.00	9.76	.44	.29	.30	32.46	3.90	.95	25.86	4.46	1.87	.24	.045			
24B	5.02	4.39	9.41	.48	.23	.23	39.78	5.57	1.30	18.56	6.36	2.56	.34	.045	8.0	72.0	20.0
44	6.45	7.95	14.40	.74	.15	.45	22.89	4.06	.91	25.66	3.78	2.26	.03	.048			
61	4.68	1.78	6.46	.23	.08	.50	57.15	5.66	1.58	15.15	6.59	1.39	.20	.015			
66	4.59	6.33	10.92	.72	.30	.44	36.82	7.18	1.28	21.27	3.45	3.14	.35	.043			
80	4.81	7.60	12.41	.75	.31	.53	32.46	5.93	1.19	19.69	4.16	3.01	.35	.053	5.7	71.9	22.4
85	7.13	4.71	11.84	.52	.18	.77	22.38	4.90	.79	35.75	2.53	2.16	.15	.035	2.4	81.6	16.0
88	4.46	7.49	11.95	.80	.25	.39	34.06	5.95	1.25	20.42	3.60	2.87	.32	.048	3.5	81.4	15.1
89	4.51	9.16	13.67	.70	.26	.50	32.52	6.55	1.20	21.29	3.77	2.91	.29	.049	15.0	69.7	15.3
Average	6.17	5.49	11.64	.55	.22	.46	29.20	4.68	.98	26.66	3.68	2.23	.22	.040	13.8	71.4	14.8
Peaty silt																	
20	3.43	16.87	20.30	1.66	.23	.96	37.62	5.28	1.23	18.36	6.21	2.36	.36	.037			
28	3.01	14.10	17.11	1.35	.13	1.02	30.61	5.97	1.35	14.52	3.24	3.03	.33	.053			
47	3.21	17.40	20.61	1.50	.31	1.01	24.33	4.88	1.04	14.03	3.11	2.74	.05	.045			
59	0.43	11.60	12.03	.70	.17	.65	28.28	4.71	1.11	24.54	4.59	2.29	.25	.023			
60	0.32	11.55	11.87	.69	.16	.56	30.35	4.55	1.14	19.55	4.90	2.12	.23	.035			
Average	2.08	14.30	16.38	1.18	.20	.84	30.24	5.08	1.17	18.20	4.41	2.51	.24	.039			
Algal silt																	
29B	4.66	7.57	12.23	.60	.22	.60	33.22	6.33	1.52	18.25	4.55	2.39	.36	.046	1.2	73.5	25.3
30	5.08	7.27	12.35	.75	.22	.64	31.32	5.79	1.49	19.47	4.54	2.48	.33	.046			
37	4.72	5.76	10.48	.60	.23	.57	36.44	7.13	1.75	17.66	5.02	2.75	.40	.044	1.5	71.7	26.8
39	3.50	7.15	10.65	.85	.38	.48	40.25	8.11	1.72	13.77	3.30	3.12	.07	.049			
49B	3.83	7.95	11.78	.33	.42	.46	36.39	7.07	1.51	15.69	3.84	3.04	.07	.060	1.4	94.2	4.4
50	4.40	6.76	11.16	.88	.25	.56	34.19	6.49	1.42	17.58	3.81	2.92	.37	.047			

Core	Cl	V	B	Cu	Co	Ni	Be	Mo	Ge	Zr	Pb	Zn	Cd
							(parts per million)						
Silt with sand and/or shells													
1	223	<30	10	18.9	3.7	40.7	<1.2	5.2	<5.7	62	60	75.4	< .5
5	177	<30	4	10.7	<3.8	31.1	<1.2	5.1	<5.7	22	51	28.4	< .5
8	266	<30	13	16.4	<3.9	19.9	<1.2	<3.3	<5.7	18	61	51.1	< .5
13	224	<30	9	12.6	<4.1	26.2	<1.2	<3.3	<5.7	47	35	40.3	< .5
24B	210	47	18	18.2	6.6	30.9	<1	2.2	<3	158	20	67.8	< .3
44	153	30	26	13.8	13.0	23.4	<1.2	<3.7	<5.7	83	45	84.3	<1.1
61	171	13	13	5.1	<3.4	<9.8	<1	<1.3	<3	40	<10	23.8	<1.1
66	105	38	27	27.5	<3.4	43.5	<1	<1.3	<3	132	26	90.7	<1.1
80	198	39	22	27.9	<3.4	29.0	<1	<1.3	<3	121	32	94.8	<1.1
85	161	<30	9	15.0	<3.5	16.7	<1.2	5.6	<5.7	39	29	80.0	< .6
88	235	34	16	24.6	3.6	29.3	<1	<1.3	<3	102	28	107	< .6
89	147	33	20	23.3	<4.1	31.8	<1	<1.3	<3	111	36	103	< .6
Average	189	<32	16	17.8	<4.7	27.7	<1.1	<2.9	<4.4	78	36	70.6	< .7
Peaty silt													
20	243	46	15	24.1	<3.6	31.8	<1.2	2.5	<3	85	36	85.7	< .3
28	259	44	36	21.4	3.5	21.2	<1	1.9	<3	72	53	81.3	< .3
47	227	<33	23	24.0	4.1	28.2	<1	1.4	<3	64	37	108	< .6
59	241	<30	16	16.9	<3.3	17.1	<1.2	4.2	<5.7	64	36	74.2	<1.1
60	187	21	17	17.4	<3.4	17.6	<1	<1.3	<3	79	37	69.4	<1.1
Average	231	<35	21	20.8	<3.6	23.2	<1.1	2.3	<3	73	40	83.7	< .7
Algal silt													
29B	178	53	34	20.0	4.4	13.9	<1.0	2.6	<3	139	71	93.7	< .3
30	261	59	28	18.5	<3.4	15.3	1.0	2.5	<3	130	88	127	< .5
37	185	69	35	23.0	5.2	15.9	1.3	3.6	<3	175	90	133	< .5
39	237	84	37	25.2	4.3	21.7	1.5	3.3	<3	100	103	149	<1.1
49B	176	45	23	24.7	<3.6	24.2	<1.0	1.9	<3	87	52	117	< .6
50	194	66	29	23.2	5.0	22.3	2.5	2.3	<3	121	51	125	< .6

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Table 2. (Continued)

Core	Inorganic carbon	Organic carbon	Total carbon	N	P_2O_5	S	SiO_2	Al_2O_3	K_2O	CaO	MgO	Fe_2O_3	TiO_2	MnO	Sand	Silt	Clay
Algal silt (continued)								(percent)									
51	5.82	5.96	11.78	.77	.22	.82	28.09	5.16	1.16	22.53	4.22	2.61	.27	.046			
55	3.42	12.44	15.86	.92	.31	.62	37.74	8.11	1.82	13.89	3.41	2.94	.42	.050			
56	5.15	7.80	12.95	.85	.29	.69	30.08	5.83	1.20	21.86	3.85	2.83	.30	.044			
58	6.09	6.45	12.54	.81	.20	.70	27.97	4.98	1.15	24.62	4.50	2.54	.28	.040			
82	4.96	7.74	12.70	.69	.27	.63	30.75	6.31	1.27	20.70	4.01	2.86	.33	.047	0.9	67.3	31.8
84	5.40	6.65	12.05	.85	.28	.62	28.53	6.19	1.30	26.12	3.22	2.65	.27	.040	2.9	66.7	30.4
98B	5.41	6.43	11.84	.76	.45	.45	32.45	5.58	1.02	27.67	2.38	2.30	.22	.037	0.6	71.5	27.9
Average	4.80	7.38	12.18	.74	.29	.60	32.88	6.39	1.41	19.96	3.90	2.73	.28	.046	1.4	74.2	24.4
Muck																	
14	3.81	9.83	13.64	.70	.42	.40	36.54	6.26	1.35	14.23	4.79	3.68	.41	.054			
18B	3.30	14.13	17.43	1.38	.25	.69	29.78	6.55	1.20	14.35	3.37	3.06	.37	.050	3.9	66.1	30.0
27	1.92	11.97	13.89	1.19	.24	.75	44.24	7.75	1.83	6.99	4.27	5.01	.45	.070			
35	1.30	15.91	17.21	1.60	.30	1.24	39.62	8.05	1.71	6.30	3.23	4.27	.48	.062			
38	2.10	9.20	11.30	.76	.71	.24	44.21	8.87	2.10	6.40	4.80	4.23	.11	.065			
48	3.54	13.14	16.68	1.33	.27	.61	30.65	6.00	1.19	13.82	3.96	2.87	.06	.048			
53	3.04	14.60	17.64	1.25	.09	.83	29.76	5.03	1.23	10.00	4.34	2.59	.30	.043			
62	0.90	26.53	27.43	2.54	.31	1.49	23.99	5.24	1.09	7.47	1.98	2.95	.35	.040			
67	3.19	7.35	10.54	.68	.48	.30	43.08	7.94	1.39	13.20	3.43	3.92	.49	.058			
Average	2.57	13.60	16.20	1.27	.34	.73	35.76	6.85	1.45	10.31	3.79	3.62	.34	.054	3.9	66.1	30.0
Marl																	
32	10.61	1.46	12.07	.15	.04	.28	5.68	0.46	0.16	49.74	1.63	0.29	.01	.007			
33	4.60	1.48	6.08	.14	.004	.42	46.09	3.40	1.07	22.68	3.77	1.10	.11	.008			
52	9.33	1.25	10.58	.03	.02	.28	14.71	1.33	0.36	42.64	2.69	0.48	.05	.007			
100	9.88	1.86	11.74	.22	.06	.62	10.14	1.34	0.16	52.27	1.51	0.55	.01	.012	34.1	54.3	11.6
101	8.05	0.65	8.70	.09	.36	.44	36.12	5.57	0.96	27.37	2.36	2.28	.22	.042	41.6	48.4	10.0
Average	8.49	1.34	9.83	.13	.10	.41	22.55	2.42	0.54	38.94	2.39	0.94	.08	.015	37.9	51.3	10.8

Core	Cl	V	B	Cu	Co	Ni	Be	Mo	Ge	Zr	Pb	Zn	Cd
Algal silt (continued)						(parts per million)							
51	175	65	20	18.0	5.6	19.8	<2.3	2.3	<3	112	46	79.5	< .7
55	197	90	38	28.6	6.0	24.7	1.5	3.2	<3	142	69	127	< .7
56	223	34	20	23.0	<3.4	24.1	<1	<1.3	<3	94	49	91.3	<1.1
58	247	34	21	19.8	5.6	19.2	<1.2	5.4	<5.7	74	44	79.4	<1.1
82	189	40	32	31.9	3.4	26.9	<1	<1.3	<3	97	48	104	<1.1
84	192	34	29	23.3	<3.2	24.6	<1.2	5.0	<5.7	60	37	97.6	< .7
98B	149	<30	16	21.0	<3.0	21.7	<1.2	<4.3	<5.7	40	48	94.4	< .6
Average	200	54	28	23.1	<4.3	21.1	<1.4	<3.0	<3	105	61	109	< .7
Muck													
14	433	64	21	84.7	4.7	29.0	1.3	2.0	<3	100	442	268	< .5
18B	188	55	25	27.7	<3.5	30.6	1.2	<1.4	<3	93	59	110	< .5
27	182	44	36	98.8	4.8	16.0	<1	2.0	<3	89	60	126	< .3
35	229	62	37	33.3	5.7	21.6	<1.2	3.5	<3	97	67	162	< .5
38	182	98	39	74.1	11.0	18.3	2.0	4.8	<3	209	282	267	<1.1
48	183	34	20	21.9	<3.5	29.1	<1	<1.3	<3	86	32	95.4	< .6
53	280	50	22	24.1	<3.4	20.4	<1	1.5	<3	88	58	95.8	< .7
62	170	30	37	21.4	<3.5	20.0	<1	<1.3	<3	37	41	101	<1.1
67	176	47	22	38.2	<3.4	90.4	<1.0	<1.3	<3	120	19	111	<1.1
Average	225	54	29	47.1	<4.8	30.6	<1.2	<2.1	<3	102	117	148	< .7
Marl													
32	238	<30	2	1.9	15.0	<4.9	<1.2	<3.3	<5.7	17	34	74.0	< .5
33	288	31	6	3.6	<3.4	<4.9	<1	<1.3	<3	35	28	40.4	< .5
52	162	<30	3	3.2	7.7	3.6	<1.2	<3.3	<5.7	<11	9	16.8	< .7
100	209	<31	10	3.4	<3.0	<6.8	<1.2	<3.3	<5.7	<11	7	40.4	< .6
101	195	<30	10	3.3	<3.0	<6.8	<1.2	<3.3	<5.7	<11	<6	32.2	< .6
Average	218	<30	6	3.1	<6.4	<5.4	<1.2	<2.9	<5.2	<17	17	40.8	< .6

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Table 2. (Concluded)

Core	Inorganic carbon	Organic carbon	Total carbon	N	P_2O_5	S	SiO_2	Al_2O_3	K_2O	CaO	MgO	Fe_2O_3	TiO_2	MnO	Sand	Silt	Clay
								(percent)									
River sand																	
17	3.20	2.63	5.83	.41	.22	.12	62.16	5.90	1.47	10.13	4.91	2.34	.35	.035			
40	3.14	8.26	11.40	.82	.13	1.87	44.79	4.83	1.27	11.23	4.82	3.64	.05	.052			
43	3.50	1.87	5.01	.22	.11	.11	60.82	5.41	1.43	9.47	5.87	1.56	.04	.034			
72	3.94	3.45	7.39	.30	.19	.40	52.27	5.57	1.36	17.55	3.19	2.24	.24	.034			
Average	3.45	4.05	7.50	.44	.16	.63	55.01	5.43	1.38	12.10	4.70	2.45	.17	.039			
Peat																	
45	3.46	20.22	26.38	1.90	.20	.67	15.94	3.10	0.71	14.40	2.61	2.07	.03	.028			
63	3.72	15.14	18.86	1.86	.34	1.40	24.66	4.43	0.82	22.16	1.53	3.46	.20	.049			
Average	3.59	17.68	21.27	1.88	.27	1.04	20.30	3.77	0.77	18.28	2.07	2.77	.12	.039			

Core	Cl	V	B	Cu	Co	Ni	Be	Mo	Ge	Zr	Pb	Zn	Cd
						(parts per million)							
River sand													
17	209	37	14	21.0	3.6	46.5	<1	<1.3	<3	141	28	52.5	<.5
40	152	37	19	10.2	<3.4	12.9	<1	5.7	<3	92	33	83.3	<1.1
43	177	17	17	6.3	<3.4	<7.4	<1	<1.3	<3	99	33	60.6	<1.1
72	104	24	11	14.8	<3.4	20.3	<1	<1.3	<3	43	28	84.3	<1.1
Average	161	29	15	13.1	<3.5	21.8	<1	<2.4	<3	94	31	70.2	<1
Peat													
45	330	34	20	18.0	<3.4	21.6	<1	<1.3	<3	44	37	76.2	<.6
63	116	32	24	15.6	3.6	11.1	<1	<1.3	<3	42	27	97.6	<1.1
Average	223	33	22	16.8	<3.5	16.4	<1	<1.3	<3	43	32	86.9	<.9

Table 3. Vertical Changes in Geochemistry of Cores of Bottom Sediments in Fox Chain of Lakes

Core depth (cm)	*Inorganic carbon*	*Organic carbon*	*Total carbon*	*N*	P_2O_5	*S*	SiO_2	Al_2O_3	K_2O	*CaO*	*MgO*	Fe_2O_3	TiO_2	*MnO*	*Sand*	*Silt*	*Clay*
Core 1 – Pistakee Lake										*(percent)*							
0-5	8.20	4.12	12.32	.46	.22	.69	18.16	2.84	0.60	36.36	3.00	1.99	.19	.047	48.1	51.7	0.2
20-25	11.21	1.79	13.00	.14	.11	.23	3.17	0.11	0.02	49.15	2.48	0.32	.01	.010	63.2	27.8	9.0
57-63	11.48	1.07	12.55	.22	.01	.27	1.46	0.01	0.01	49.95	2.47	0.42	.01	.010	45.3	54.7	0.0
Core 18B – Dredged Channel																	
0-6	3.30	14.13	17.43	1.38	.25	.69	29.78	6.55	1.20	14.35	3.37	3.06	.37	.050	3.9	66.1	30.0
25-30	3.43	13.15	16.58	.42	.41	.77	32.89	6.39	1.22	15.41	3.09	2.78	.39	.040	3.7	68.3	28.0
50-57	1.87	20.83	22.70	2.14	.29	1.07	27.11	5.81	1.08	9.98	2.61	2.82	.37	.042	14.6	59.4	26.0
70-75	7.52	3.55	11.07	.45	.07	.62	24.18	2.60	.62	33.42	2.37	1.38	.16	.015	8.2	72.8	19.0
90-94	6.66	4.24	10.90	.40	.09	.79	26.44	4.36	1.00	28.44	3.20	2.24	.24	.030	10.0	66.0	24.0
Core 20 – Grass Lake																	
0-6	3.43	16.87	20.30	1.66	.23	.96	37.62	5.28	1.23	18.36	6.21	2.36	.36	.037			
6-12	3.42	16.32	19.14	1.56	.33	.98	25.26	5.20	1.06	15.78	3.12	2.94	.32	.040			
25-30	2.44	19.93	22.37	1.85	.27	1.37	22.32	4.40	0.83	11.63	2.45	2.68	.25	.041			
50-55	2.52	24.47	26.99	2.15	.23	.68	21.23	3.47	0.70	13.28	2.37	2.07	.21	.030			
71-75	9.77	4.68	14.45	.41	.01	.55	6.77	0.99	0.18	44.55	2.64	0.83	.02	.014			
Core 24B – Grass Lake																	
0-7	5.02	4.39	9.41	.48	.23	.23	39.78	5.57	1.30	18.56	6.36	2.56	.34	.045	8.0	72.0	20.0
7-14	5.22	4.33	9.55	.43	.19	.27	37.22	5.30	1.23	18.31	6.16	2.45	.36	.039	10.0	74.0	16.0
14-21	5.56	4.17	9.73	.31	.18	.30	36.22	4.78	1.20	20.52	6.27	2.43	.30	.036	12.7	70.3	17.0
30-35	5.44	7.86	13.30	.39	.18	.25	28.20	5.10	1.15	22.92	4.47	2.41	.31	.044	8.6	69.6	22.0
54-59	5.50	8.05	13.55	.66	.12	.27	26.89	5.19	1.16	22.89	4.10	2.52	.26	.045	13.6	69.4	17.0

Core depth (cm)	*Cl*	*V*	*B*	*Cu*	*Co*	*Ni*	*Be*	*Mo*	*Ge*	*Zr*	*Pb*	*Zn*	*Cd*	*Hg*
Core 1 – Pistakee Lake							*(parts per million)*							
0-5	223	<30	10	18.9	3.7	40.7	<1.2	5.2	<5.7	62	60	75.4	<.5	
20-25	295	<30	0.3	3.1	<3.7	< 3.3	<1.2	<3.3	<5.7	<11	30	1.9	<.5	
57-63	175	<30	2	3.3	<4.1	< 3.3	<1.2	<3.3	<5.7	<11	27	17.5	<.5	
Core 18B – Dredged Channel														
0-6	188	55	25	27.7	<3.5	30.6	1.2	<1.4	<3	93	59	110	<.5	
25-30	286	56	25	27.8	4.6	30.8	1.0	<1.3	<3	86	40	89.3	<.5	
50-57	289	46	29	22.4	<3.8	26.3	<1	1.3	<3	46	51	82.9	<.5	
70-75	150	<30	15	7.5	12.0	< 4.1	<1.2	4.8	<5.7	62	<4	16.1	<.3	
90-94	131	<30	17	11.5	14.0	8.6	<1.2	8.1	<5.7	70	<4	59.0	<.3	
Core 20 – Grass Lake														
0-6	243	46	15	24.1	<3.6	31.8	1.2	2.5	3	85	36	85.7	<.3	
6-12	268	45	19	25.1	4.2	33.3	<1	<1.3	<3	66	36	86.0	<.3	
25-30	278	33	17	20.3	<3.4	13.1	<1	1.9	<3	46	773	70.0	<.3	
50-55	258	29	13	13.9	4.1	8.1	<1	<1.3	<3	35	<4	29.5	<.3	
71-75	221	<30	10	4.8	15.0	4.3	<1.2	<3.3	<5.7	< 11	<4	5.7	<.3	
Core 24B – Grass Lake														
0-7	210	47	18	18.2	6.6	30.9	<1	2.2	<3	158	20	67.8	<.3	
7-14	302	48	21	18.0	<3.7	30.6	<1	<1.3	<3	149	20	63.3	<.3	
14-21	221	47	19	14.6	6.1	24.3	<1	2.2	<3	142	18	62.3	<.3	
30-35	168	65	24	10.9	4.5	8.8	<1	2.2	<3	128	<3	46.2	<.3	
54-59	140	54	22	12.6	<4.1	9.6	<1	2.2	<3	113	<3	90.8	<.3	

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Table 3. (Continued)

Core depth (cm)	Inorganic carbon	Organic carbon	Total carbon	N	P_2O_5	S	SiO_2	Al_2O_3	K_2O	CaO	MgO	Fe_2O_3	TiO_2	MnO	Sand	Silt	Clay
Core 29B – Channel Lake										(percent)							
0-5	4.66	7.57	12.23	.60	.22	.60	33.22	6.33	1.52	18.25	4.55	2.39	.36	.046	1.2	73.5	25.3
5-10	4.81	7.66	12.47	.74	.22	.58	34.52	6.46	1.63	18.20	4.50	2.46	.38	.035	1.1	64.6	34.3
10-15	4.53	5.63	10.16	.68	.22	.57	37.36	7.04	1.72	16.56	4.41	2.57	.37	.047	1.2	68.3	30.5
20-25	3.98	6.36	10.34	.70	.24	.58	38.59	7.37	1.77	15.56	4.43	2.92	.40	.052	1.4	65.0	33.6
40-45	2.72	8.86	11.58	1.10	.20	.29	39.87	8.44	2.24	8.42	5.01	5.37	.50	.066	6.0	59.9	34.1
65-70	3.10	7.43	10.53	.61	.25	.24	40.33	7.84	2.18	11.32	4.80	4.35	.46	.064	3.5	68.7	27.8
Core 37 – Lake Catherine																	
0-6	4.72	5.76	10.48	.60	.23	.57	36.44	7.13	1.75	17.66	5.02	2.75	.40	.044	1.5	71.7	26.8
6-12	4.65	4.73	9.38	2.40	.13	.54	37.45	7.56	1.86	17.34	5.83	1.86	.41	.045	1.1	71.5	27.4
12-18	4.68	1.86	6.54	.43	.16	.21	42.02	9.09	2.39	13.96	7.06	3.21	.55	.045	0	63.2	36.8
18-25	4.26	3.97	8.23	.45	.18	.48	40.32	8.68	2.05	14.63	4.98	3.17	.09	.049	1.3	67.8	30.9
40-45	3.92	5.85	9.77	.59	.23	.40	39.28	8.24	1.94	14.57	4.48	3.17	.08	.055	2.7	70.5	26.8
60-65	3.40	6.75	9.97	.71	.20	.26	42.00	8.58	2.14	11.62	5.01	4.34	.09	.069	1.0	64.6	34.4
Core 43 – Fox River																	
0-8	3.50	1.87	5.01	.22	.11	.11	60.82	5.41	1.43	9.47	5.87	1.56	.04	.034			
15-20	3.84	3.00	6.84	.25	.17	.14	50.23	5.77	1.44	10.96	6.33	2.18	.06	.034			
25-30	3.99	4.05	8.04	.40	.29	.16	47.38	6.24	1.44	11.86	6.49	2.52	.07	.035			
35-40	4.27	3.49	7.76	.28	.18	.15	45.88	6.02	1.44	12.73	6.52	2.25	.07	.037			
Core 49B – Lake Marie																	
0-5	3.83	7.95	11.78	.33	.42	.46	36.39	7.07	1.51	15.69	3.84	3.04	.07	.060	1.4	94.2	4.4
5-9	3.95	7.76	11.71	.87	.43	.48	36.93	7.33	1.55	15.98	3.76	2.96	.07	.048	0.8	94.6	4.6
9-13	4.21	7.72	11.93	.95	.36	.52	34.94	6.76	1.47	16.32	3.44	2.84	.07	.049	1.7	93.9	4.4
20-25	4.27	7.35	11.62	.88	.30	.52	34.39	6.04	1.34	17.10	3.56	2.67	.06	.047	0.7	56.7	42.6
50-55	4.36	5.49	9.85	.69	.18	.56	38.30	7.53	1.75	16.33	4.21	2.92	.39	.051	0.4	64.0	35.6
79-84	3.79	7.90	11.69	.80	.18	.39	36.52	7.53	1.94	14.11	4.24	3.96	.43	.068	1.6	64.8	33.6

Core depth (cm)	Cl	V	B	Cu	Co	Ni	Be	Mo	Ge	Zr	Pb	Zn	Cd	Hg
Core 29B – Channel Lake								(parts per million)						
0-5	178	53	34	20.0	4.4	13.9	<1.0	2.6	<3	139	71	93.7	< .3	
5-10	315	63	30	19.6	4.6	14.1	1.2	3.5	<3	138	71	92.8	< .3	
10-15	280	55	32	19.1	4.4	13.9	1.3	3.3	<3	136	57	95.4	< .3	
20-25	175	67	34	17.0	5.4	11.3	1.4	3.6	<3	162	33	82.5	< .3	
40-45	202	67	45	18.5	7.6	15.2	1.4	4.3	<3	118	< 3	62.1	< .3	
65-70	295	66	43	18.5	6.0	19.2	1.5	3.9	<3	143	20	87.3	< .5	
Core 37 – Lake Catherine														
0-6	185	69	35	23.0	5.2	15.9	1.3	3.6	<3	175	90	133	< .5	
6-12	286	70	37	21.4	6.2	16.6	1.4	3.9	<3	179	76	114	< .5	
12-18	136	82	39	20.7	7.0	20.1	1.6	4.1	<3	233	42	79.8	< .5	
18-25	162	82	43	21.2	6.7	16.1	1.5	2.6	<3	197	74	117	< .5	
40-45	153	104	36	17.6	9.5	17.6	1.6	4.7	<3	169	39	87.3	<1.1	
60-65	236	94	42	16.0	7.4	19.0	1.7	5.2	<3	169	24	73.5	<1.1	
Core 43 – Fox River														
0-8	177	17	17	6.3	<3.4	<7.4	<1	<1.3	<3	99	33	60.6	<1.1	
15-20	209	47	23	14.2	<3.6	14.9	<1	<1.3	<3	130	39	85.7	<1.1	
25-30	235	42	20	18.0	4.8	26.8	<1	2.4	<3	173	43	101	<1.1	
35-40	191	36	18	12.8	4.0	17.9	<1	1.5	<3	121	40	79.5	<1.1	
Core 49B – Lake Marie														
0-5	176	45	23	24.7	<3.6	24.2	<1	1.9	<3	87	52	117	< .6	
5-9	186	39	21	24.6	4.2	24.5	<1	2.2	<3	104	55	120	< .6	
9-13	201	55	26	25.9	<3.4	25.4	<1	2.0	<3	104	114	164	< .6	
20-25	257	60	25	22.8	3.5	20.8	<1	2.0	<3	94	56	110	< .8	
50-55	204	90	29	20.5	6.0	18.5	<1.9	4.4	<3	163	45	112	< .6	
79-84	207	86	35	20.4	7.4	15.3	2.9	4.1	<3	156	7	82.4	< .6	

(Continued on next page)

Table 3. (Continued)

Core depth (cm)	*Inorganic carbon*	*Organic carbon*	*Total carbon*	*N*	*P_2O_5*	*S*	*SiO_2*	*Al_2O_3*	*K_2O*	*CaO*	*MgO*	*Fe_2O_3*	*TiO_2*	*MnO*	*Sand*	*Silt*	*Clay*
Core 55 – Petite Lake										*(percent)*							
0-2	3.42	12.44	15.86	.92	.31	.62	37.74	8.11	1.82	13.89	3.41	2.94	.42	.050			
2-6	3.40	9.31	12.71	.96	.31	.70	38.29	7.77	1.75	14.46	3.59	3.20	.46	.050			
6-10	3.39	8.95	12.34	.65	.36	.63	35.63	7.75	1.72	14.14	3.41	3.20	.52	.046			
15-20	4.14	8.05	12.19	.92	.32	.64	35.09	6.90	1.59	16.94	3.45	2.64	.34	.045			
35-40	3.42	7.14	10.56	1.99	.19	.70	41.66	8.76	1.98	14.09	3.04	3.44	.46	.065			
80-85	2.75	15.57	18.32	1.68	.22	1.07	33.43	4.28	0.72	13.90	3.04	2.58	.24	.029			
Core 56 – Fox Lake																	
0-4	5.15	7.80	12.95	.85	.29	.69	30.08	5.83	1.20	21.86	3.85	2.83	.30	.044			
4-8	5.10	8.23	13.33	.89	.27	.71	29.45	5.68	1.17	21.41	4.06	2.92	.30	.049			
8-13	5.08	7.83	12.91	.83	.26	.72	31.00	6.00	1.26	23.09	4.13	3.21	.31	.059			
15-20	5.28	6.86	12.14	.95	.16	.70	29.24	5.89	1.27	21.93	4.29	2.80	.31	.048			
35-40	4.93	7.21	12.14	.93	.13	.72	32.73	6.38	1.42	19.93	3.67	3.12	.33	.054			
55-60	5.92	7.77	13.69	1.00	.12	.59	26.16	4.88	1.05	25.71	3.50	2.34	.23	.043			
Core 80 – Nippersink Lake																	
0-5	4.81	7.60	12.41	.75	.31	.53	32.46	5.93	1.19	19.69	4.16	3.01	.35	.053	5.7	71.9	22.4
10-15	4.67	8.19	12.86	.45	.28	.52	33.66	5.85	1.24	19.52	4.16	2.91	.35	.041	7.6	70.0	22.4
20-25	5.94	7.10	13.04	.66	.32	.71	25.89	4.96	1.00	25.76	3.51	2.71	.23	.046	15.2	59.8	25.0
40-45	4.49	16.42	20.91	.95	.12	.57	22.15	3.79	0.76	20.63	2.57	1.96	.18	.028	7.0	66.8	26.2
Core 88 – Channel between Fox and Nippersink Lakes																	
0-5	4.46	7.49	11.95	.80	.25	.39	34.06	5.95	1.25	20.42	3.60	2.87	.32	.048	3.5	81.4	15.1
45-50	4.04	9.43	13.47	.13	.34	.49	34.84	6.39	1.35	18.61	3.33	3.28	.36	.047	4.8	77.1	18.1

Core depth (cm)	*Cl*	*V*	*B*	*Cu*	*Co*	*Ni*	*Be*	*Mo*	*Ge*	*Zr*	*Pb*	*Zn*	*Cd*	*Hg*
Core 55 – Petite Lake						*(parts per million)*								
0-2	197	90	38	28.6	6.0	24.7	1.5	3.2	<3	142	69	127	< .7	
2-6	218	30	35	28.2	<3.7	23.8	1.1	<1.4	<3	98	69	126	< .7	
6-10	271	41	33	27.5	3.6	24.1	1.3	<1.3	<3	104	79	121	< .7	
15-20	253	40	28	25.3	<3.4	24.1	<1	<1.3	<3	103	64	109	< .7	
35-40	239	51	40	26.5	<3.4	20.9	1.3	<1.3	<3	116	62	114	< .7	
80-85	303	18	31	16.1	<3.4	10.2	<1	<1.3	<3	24	< 7	464	< .7	
Core 56 – Fox Lake														
0-4	223	34	20	23.0	<3.4	24.1	<1	<1.3	<3	94	49	91.3	<1.1	.22
4-8	191	36	24	23.0	<3.4	27.3	<1	<1.3	<3	94	43	90.2	<1.1	.22
8-13	214	35	18	21.8	<3.4	25.5	<1	<1.3	<3	96	42	89.3	<1.1	.19
15-20	197	38	22	20.1	<3.4	23.5	<1	<1.3	<3	95	30	87.7	<1.1	.20
35-40	208	39	33	19.3	<3.4	15.2	<1	<1.3	<3	94	29	82.9	<1.1	.26
55-60	201	<35	22	14.3	<4.1	11.4	<1.2	<4.2	<5.7	45	15	51.6	<1.1	.15
Core 80 – Nippersink Lake														
0-5	198	39	22	27.9	<3.4	29.0	<1	<1.3	<3	121	32	94.8	<1.1	
10-15	192	35	19	24.5	<3.8	30.9	<1	<1.3	<3	129	33	97.4	<1.1	
20-25	240	<32	19	18.5	<3.9	24.0	<1.2	5.9	<5.7	61	32	77.0	<1.1	
40-45	231	25	13	14.3	4.4	12.4	<1	<1.3	<3	32	<12	42.4	<1.1	
Core 88 – Channel between Fox and Nippersink Lakes														
0-5	235	34	16	24.6	3.6	29.3	<1	<1.3	<3	102	28	107	< .6	
45-50	154	33	20	25.7	3.5	32.4	<1	<1.3	<3	101	37	111	< .6	

(Concluded on next page)

Table 3. (Concluded)

Core depth (cm)	*Inorganic carbon*	*Organic carbon*	*Total carbon*	*N*	*P_2O_5*	*S*	*SiO_2*	*Al_2O_3*	*K_2O*	*CaO*	*MgO*	*Fe_2O_3*	*TiO_2*	*MnO*	*Sand*	*Silt*	*Clay*
										(percent)							
Core 98B – Pistakee Bay																	
0-4	5.41	6.43	11.84	.76	.45	.45	32.45	5.58	1.02	27.67	2.38	2.30	.22	.037	0.6	71.5	27.9
4-8	5.48	6.91	12.39	.46	.47	.48	31.50	5.31	1.05	27.13	2.09	2.34	.23	.041	1.3	63.2	35.5
8-12	5.53	6.44	11.97	.72	.47	.48	31.13	6.30	1.02	27.50	1.92	2.33	.23	.037	2.5	59.9	37.6
35-40	5.34	5.66	11.00	.65	.04	.62	38.37	1.60	0.53	35.39	1.37	0.67	.01	.010	1.6	66.5	31.9
70-75	6.41	7.17	13.58	.79	.21	.36	26.85	2.37	0.52	31.69	1.80	1.93	.07	.033	5.1	81.1	13.8

Core depth (cm)	*Cl*	*V*	*B*	*Cu*	*Co*	*Ni*	*Be*	*Mo*	*Ge*	*Zr*	*Pb*	*Zn*	*Cd*	*Hg*
Core 98B – Pistakee Bay							*(parts per million)*							
0-4	149	<30	16	21.0	<3.0	21.7	<1.2	<4.3	<5.7	40	48	94.4	<.6	.11
4-8	182	<31	29	21.9	<3.3	24.3	<1.2	4.6	<5.7	49	47	106	<.6	.23
8-12	163	<30	28	21.4	<3.1	25.3	<1.2	4.2	<5.7	43	47	104	<.6	.22
35-40	138	<33	22	22.5	<3.0	14.9	<1.2	4.9	<5.7	36	59	113	<.6	.50
70-75	134	<30	9	7.0	4.2	<6.8	<1.2	<3.6	<5.7	25	< 6	36.9	<.6	.29

it does in Fox and Pistakee Lakes. The algal silt averages 74 percent silt and contains less than 3 percent sand (table 2). The organic components constitute about 7 percent of the sediment and, except for the fine, thread-like algal filaments that are abundant, the organic debris is very finely comminuted.

Marl

A type of sediment found in small areas of some lakes is marl. Marl is a light gray sediment consisting of a mixture of calcarenite (sand-sized fragments of organically precipitated calcium carbonate), shell debris, and, commonly, minor amounts of plant debris (table 2). Marl generally occurs in a narrow band around the margin of lake basins that are more than 4 meters (13.1 feet) deep (figure 2). The marl forms in a zone with water depths of between 2 and 4 meters (6.6 and 13.1 feet) lying between the algal silts of the deep water and the near-shore silty sediments.

Marl deposition is best developed in Channel Lake, Lakes Catherine and Marie, and in Pistakee Bay, all of which have deep water basins. It may also be present in Bluff and Petite Lakes [both contain water over 4 meters (13.1 feet) deep] but no samples were taken in the marl zones in those lakes. No active marl deposition is known to be taking place in the shallower lakes – Fox, Grass, Nippersink, and Pistakee (except Pistakee Bay) – where organic sedimentation predominates. However, older marls were encountered in these shallower lakes under more recent peaty sediments, indicating that marl deposition may have been more widespread in the past.

River Sediments

Samples from the channel of the Fox River and Nippersink Creek contain coarse-grained quartz sand. The river sediments are much coarser grained than any of the lake sediments and they also contain coarse shell debris, including large bivalves. The organic content of the river sands is generally low, consisting of a small amount of coarse plant debris. The silica content, most of it in the form of quartz, is higher in this type of sediment than in the other types (table 2).

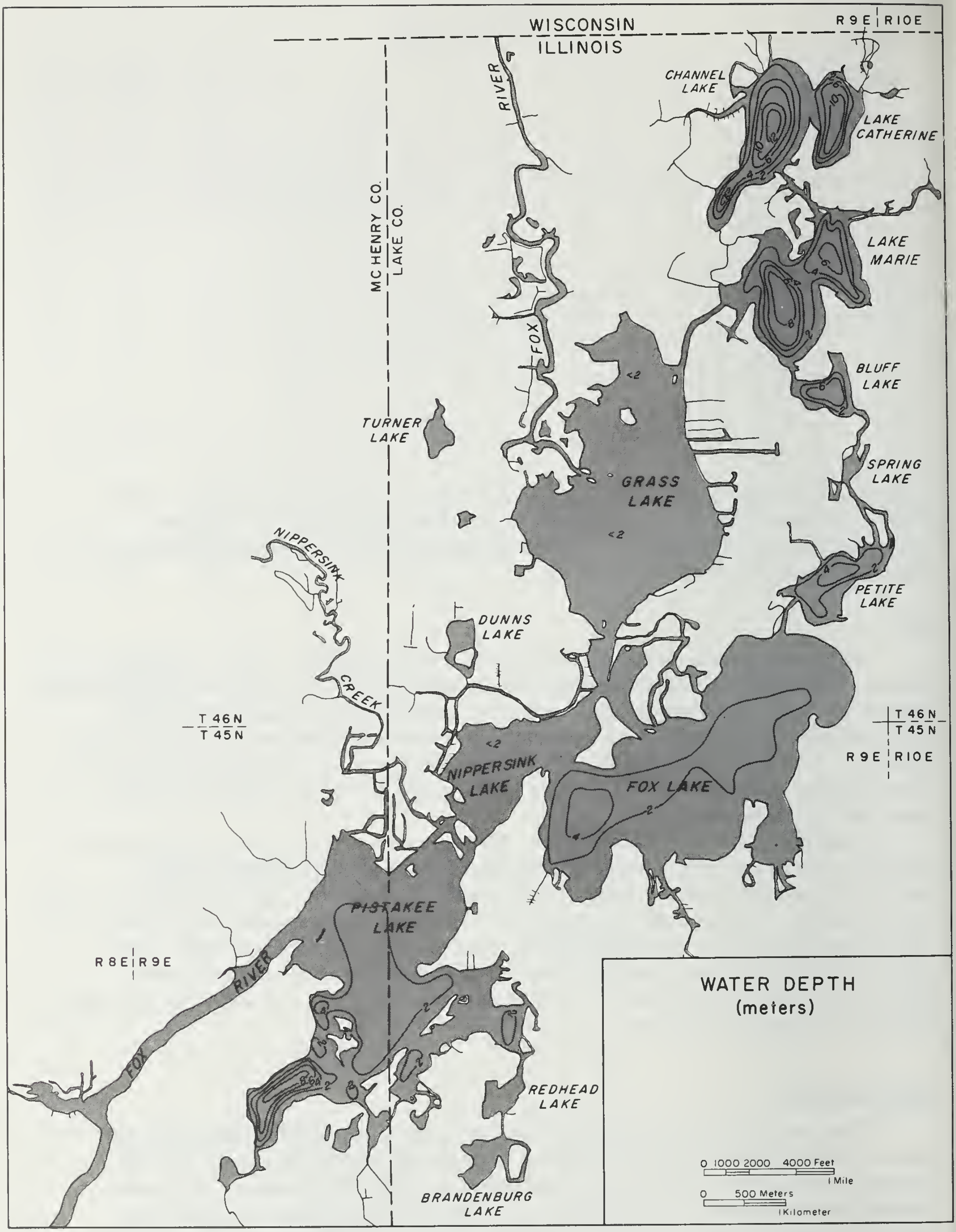

Figure 3. Water depth in the Fox Chain of Lakes

Dredged Channel Sediments

Dead-end channels, dredged to provide water access to the lake for property owners, are typically filled with a soft black muck (figure 2). The muck is mainly silt but contains up to 26 percent organic carbon (table 2). The organic components consist of algae, comminuted and decomposed leaves and marsh plant fragments from channel-side vegetation, and organic material from septic tank outfalls. The carbonate content of muck is low and shells are scarce (table 2). Because the dredging dates are known for many of the channels, the accumulation of sediment can be measured. In one channel, dredged 10 years before, 0.36 meters (1.2 feet) of sediment had accumulated.

Peat

In Grass Lake and in other places where older peat was found, peat is generally covered by a thin layer of peaty silt. However, in two cores, the older peat was exposed at the lake floor. Peat, which contains less inorganic sediment and more coarse organic fragments than the peaty silt (table 1), is now accumulating in the widespread cattail marshes that surround parts of the Chain of Lakes (figure 2).

Glacial Deposits

Gray glacial till underlies most of the lakes. As the glacial ice melted, glacial-lacustrine clay accumulated above the glacial till. These sediments probably occur deep under the younger silts and marls in the Chain of Lakes but were encountered in only a few places during coring. The deeper lakes commonly have steep underwater slopes, which may be too steep for sediments to collect. The older glacial-sediment floor of the lake is exposed in these places. Where the lake floor has been eroded, or where no deposition has occurred, the old glacial sediments may be at or near the lake floor (figure 2). None of the glacial sediments was analyzed. The older sediments, particularly the till compressed by the weight of the glacial ice, are compact and provide the best foundations for construction of large buildings, docks, or sheet pilings.

PALYNOLOGY

Ambrosia (ragweed) pollen generally constitutes less than 10 percent of the total pollen found in samples of Holocene lake sediments. However, in the most recent sediments *Ambrosia* pollen content may form up to 40 percent of the pollen preserved. The dramatic increase in *Ambrosia* pollen takes place over only a few centimeters vertically in the typical core. The sudden increase marks the first effects of large-scale clearing of forest cover for the establishment of agriculture in the Midwest. This is generally considered, on the basis of historical records, to have taken place between 1830 and 1840 in northern Illinois. When a forest is cut, the abundance of ragweed increases dramatically because it grows well on cleared and disturbed land.

The base of the *Ambrosia* zone as preserved in the sediments of the Chain of Lakes is therefore an important marker horizon, indicating the position of the sediment-water interface about 1840 (James King, personal communication, 1976). This date can be used to compute sedimentation rates in the lakes from 1840 to 1975 in three cores that were analyzed (figures 4, 5, and 6).

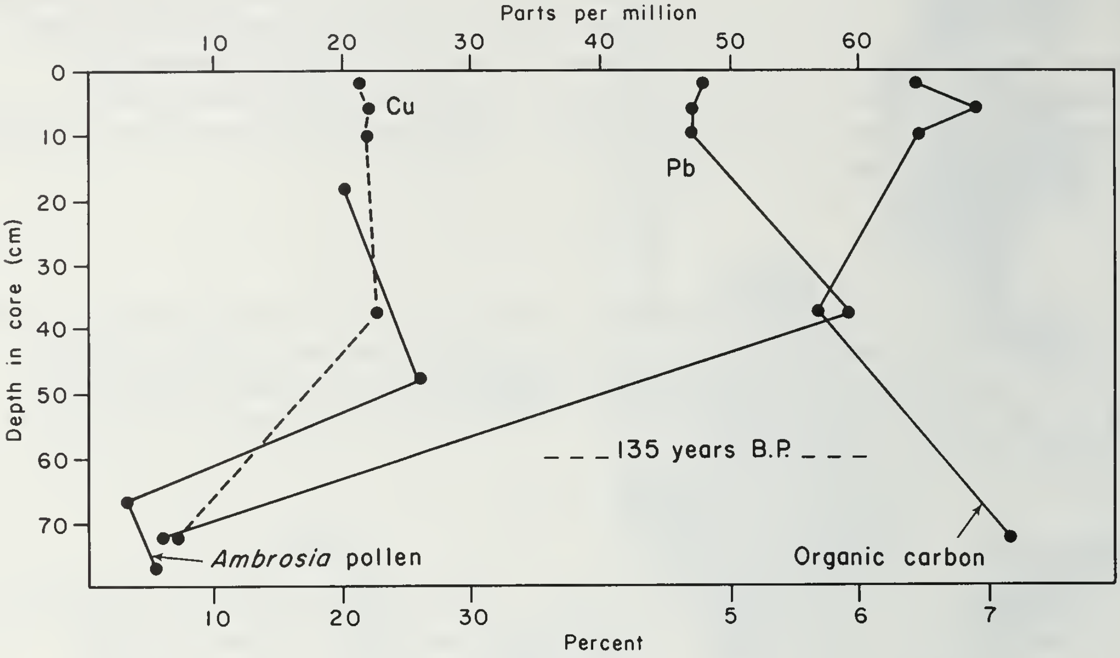

Figure 4. Depth profile for core 98B from Pistakee Bay

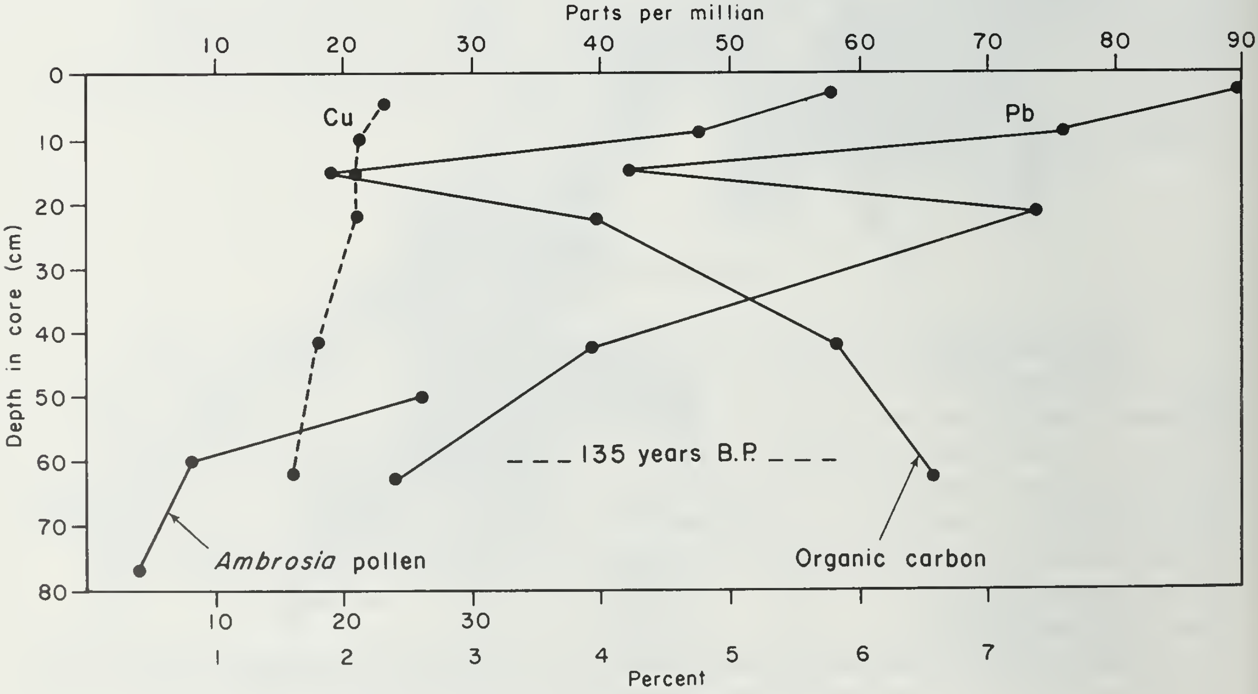

Figure 5. Depth profile for core 37 from Lake Catherine

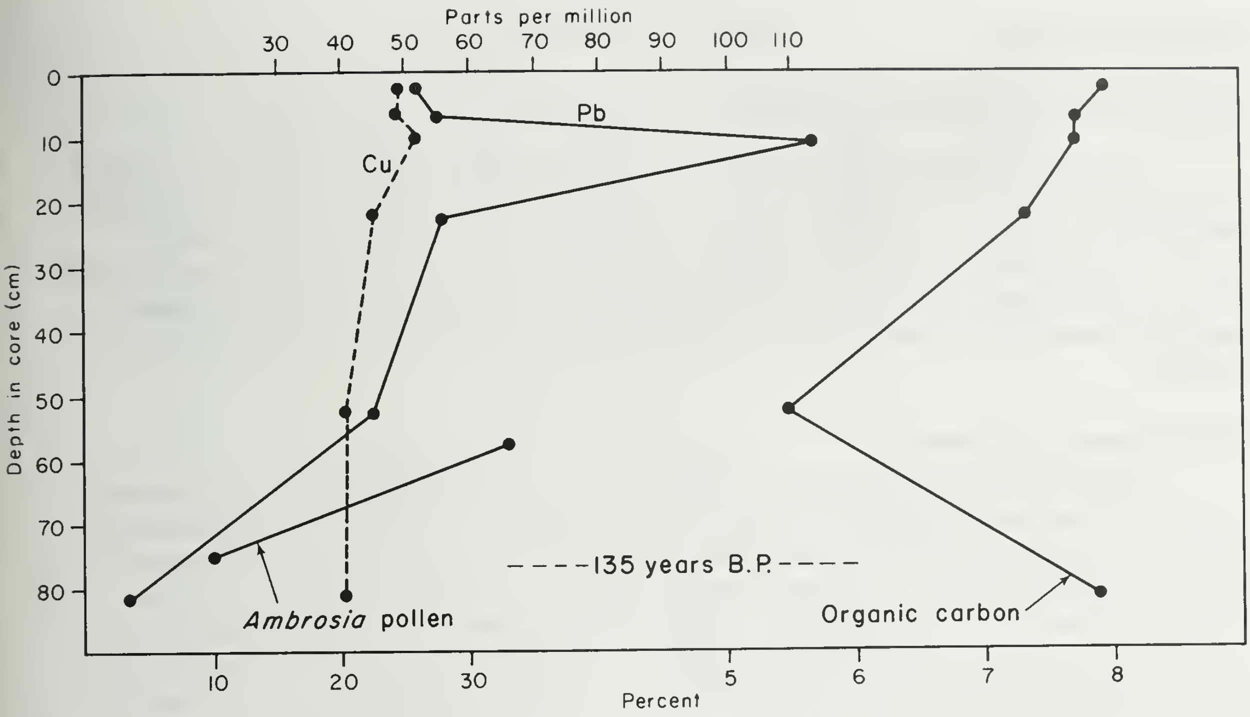

Figure 6. Depth profile for core 49B from Lake Marie

Sedimentation rates in Lake Catherine are about 0.41 centimeters per year (cm/yr) (0.16 inch), in Lake Marie about 0.48 cm/yr (0.19 inch), and in Pistakee Bay about 0.44 cm/yr (0.17 inch). These rates are several times higher than Lake Michigan rates of 0.05 to 0.10 cm/yr (0.02 to 0.04 inch/year) (King, et al., 1976).

SEDIMENT GEOCHEMISTRY

Sediment samples from several levels in 12 cores were analyzed geochemically for 27 major and minor components to determine the vertical variations in the recent sediments (table 3). The base of the *Ambrosia* (ragweed) pollen zone was determined for three cores. Samples from the surface layer at an additional 37 locations were analyzed to determine areal distribution of the components (table 2).

Geochemical studies of Lake Michigan sediments (Shimp et al., 1971; Lineback and Gross, 1972) show that some elements that occur in lake sediments in trace amounts (e.g., lead, zinc, and copper) are more abundant in the surface sediment layers than in older layers. This pattern of accumulation in recently deposited sediments has been interpreted as being the result of man-caused pollution of the lake environment. Heavy metals and other pollutants may enter a lake via the air (e.g., lead from automobile exhaust) or via water from industrial, agricultural or domestic sources. In Lake Michigan all excessive concentrations occur above the base of the *Ambrosia* pollen zone – that is, in sediment deposited since 1840 and the highest concentrations are in the most recent sediments. The depth to the base of the *Ambrosia* zone in Lake Michigan is 5 to 15 centimeters (2 to 6 inches).

Analytical Techniques

X-ray Fluorescence Spectrometry and Carbon Determination

The analytical procedure followed for the determination of major and minor elements in sediments by x-ray fluorescence spectrometry (XRF) and the methods used to determine total carbon, organic carbon, and inorganic carbon (CO_2) have been reported by Shimp et al. (1970). Since their work, the sensitivity of the XRF equipment has been increased for the light elements by using a thallium acid phthalate (TIAP) crystal in place of the previously used ammonium dihydrogen phosphate (ADP) and ethylene diamine ditartrate (EDDT) crystals.

Optical Emission Spectrography

Two synthetic standards were prepared for use in determining trace-element concentrations in these sediments by optical emission spectrography. It was felt that the sediments would be represented by two general matrix types, those containing low concentrations of calcium carbonate ($CaCO_3$) and those with high calcium carbonate concentrations. After the concentrations of major constituents in approximately two-thirds of the samples had been determined by x-ray fluorescence spectrometry, the calcium carbonate concentrations were listed in increasing order. A natural division in $CaCO_3$ concentrations occurred between 36.64 percent and 40.23 percent. The first set of synthetic standards, which had been prepared previously for the analysis of other lake bottom sediments, contains 21.48 percent $CaCO_3$. Concentrations of the major constituents are listed in table 4.

Table 4. Major Constituents in Synthetic Standard Matrices for Sediments

Constituent	*Concentrations (%)* Low $CaCO_3$	*Concentrations (%)* High $CaCO_3$
Al_2O_3	7.38	2.24
$CaCO_3$	21.48	76.44
SiO_2	54.06	16.36
Fe_2O_3	3.44	1.35
MgO	8.98	2.87
Na_2CO_3	1.18	
K_2CO_3	3.48	0.74

The composition of the matrix low in calcium carbonate was determined by knowing the mean composition of several hundred previously analyzed bottom sediment samples from Lake Michigan. The matrix with a composition high in calcium carbonate was determined from the mean composition of the Chain of Lakes bottom sediments that contain more than 40.23 percent $CaCO_3$.

To the first (low $CaCO_3$) matrix type, amounts of Spex Industries, Inc., alumina (Al_2O_3) and silica (SiO_2) Spex Time Saver Standards containing 1000, 333, 100, and 33 parts per million (ppm) of 49 different elements were added in the same ratio as the SiO_2:Al_2O_3 ratio in the matrix. The final concentrations of the trace metals were 333, 100, 33.3, 10.0, 3.3, and 1.0 ppm. There was a corresponding decrease in concentrations of major elements due to additions of the Spex standards, but it did not significantly affect the behavior of the standards in the arc nor the ability of the standards to approximate the samples. The procedure used for the high calcium carbonate matrix was similar, but $CaCO_3$ Spex Time Saver Standards were used. The weights of each standard used are listed in table 5.

Each standard mixture was ground thoroughly with a mullite mortar and pestle under absolute ethanol to increase the homogeneity of the individual standards. Studies of time vs. intensity spectra were made for both standard matrices to determine the proper exposure times. The experimental parameters chosen are listed in table 6.

The percent transmittance values of the desired spectrographic lines on the developed photographic plates were determined by standard densitometry. Intensities were determined

Table 5. Compositions of Standards

Weight of synthetic matrix (grams)	*Low $CaCO_3$ matrix*				*High $CaCO_3$ matrix*		*Final standard concentrations (ppm)*
	SiO_2 Spex time saver standard		*Al_2O_3 Spex time saver standard*		*$CaCO_3$ Spex time saver standard*		
	(mg)	*(ppm)*	*(mg)*	*(ppm)*	*(mg)*	*(ppm)*	
0.33333	146	1000	20	1000	166	1000	333
0.45000	44	1000	6	1000	50	1000	100
0.45000	44	333	6	333	50	333	33.3
0.45000	44	100	6	100	50	100	10.0
0.45000	44	33.3	6	33.3	50	33.3	3.3
0.45000	44	10.0	6	10.0			1.0

Table 6. Experimental Spectrographic Parameters

Arc gap	4 mm
Exposure time	100 sec for low $CaCO_3$, 110 sec for high $CaCO_3$
Arc current	10 A
Sample electrode	National L-3903
Counter electrode	National SP-1009
Atmosphere and flow rate	80% argon, 20% oxygen at 14 SCFH
Photographic emulsion	Eastman-Kodak SA-1
Photographic developer	Eastman-Kodak D-19
Step sector	6 step, 2:1 step ratio
Slit width	10 μm
Internal standard	none
Electrode charge	20 mg
Sample mixture	1 part sample, 4 parts SP-2X graphite powder

via Hurter–Driffield emulsion calibration curves. However, the data reduction steps have been computer programmed, by means of a spline function routine to fit the Hurter–Driffield curves with points spaced every 2 percent transmittance. The individual element working curves (intensity vs. concentration) have been fitted by either first or second degree least-squares regressions or by combinations of the two types.

Atomic Absorption Spectrometry

The atomic absorption spectrometric techniques used were similar to those described by Ruch et al. (1974), except that 125-ml or 60-ml linear polyethylene bottles that had been washed in HNO_3 were substituted for the stainless steel, Teflon-lined pressure decomposition bombs. The sample and reagents were added to the bottle, which was sealed and then heated on a steam bath for 3 to 4 hours, being swirled occasionally. The only difference noted between duplicate coal-ash samples decomposed in polyethylene bottles and those decomposed in Teflon-lined bombs was a zinc blank of about 0.02 mg/ml.

Instrumental Neutron Activation Analysis

The samples were irradiated in the Advanced TRIGA reactor at the University of Illinois in a flux of 1.4×10^{12} thermal neutrons cm^{-2} sec^{-1}. The sediment samples (0.6 to 1 g) were weighed into two-fifths dram polyethylene snap-cap vials which had been previously cleaned with deionized water and acetone. The vials were heat-sealed. Multi-element standards were prepared by pipetting aliquots of standard solutions (made from a spectroscopically pure grade of each element or its compound) onto standard cellulose ash-free filter paper. The dried filters were sealed in small polyethylene bags, and these in turn were heat-sealed in clean 2-dram polyethylene vials. The vials containing the sediments were also encapsulated in 2-dram vials. During irradiation the vials were rotated at 1 rpm to ensure all samples and standards had equal neutron flux.

To determine elements that give rise to short-lived isotopes by (n,γ) reactions upon irradiation, the samples and a standard were irradiated for 10 minutes. After a 3-hour decay period, the gamma activities were counted for 2000 to 3000 seconds. The following elements were measured via their isotopes (the γ-ray lines used are in parentheses): ^{165}Dy (94.7, 361.5 keV), ^{139}Ba (165.8), ^{87m}Sr (388.4), ^{69m}Zn (438.7), ^{56}Mn (846.8, 1810.9), ^{24}Na (1368.6), and ^{42}K (1524.7). [In the symbol defining an isotope of an element, the mass number (protons + neutrons) is written as a superscript to the elemental symbol. Metastable isotopes (e.g., ^{69m}Zn) occur in energy states above the ground state (i.e., ^{69}Zn). Each radioactive isotope in decay emits γ rays of characteristic energy, measured in keV.]

To determine those elements that give rise to intermediate-lived isotopes upon irradiation, a set of samples and standards was irradiated for 2 hours. After a 26-hour decay, 5000 to 8000 second counts of the gamma activities of the samples and standards were made in a 2-day period. The following elements were determined via their isotopes as listed: ^{153}Sm (103.2 keV), ^{177}Lu (208.4, 113), ^{152m}Eu (121.8, 963.1), ^{47}Ca (1297) and Ca via the daughter ^{47}Sc (160.0), ^{175}Yb (396.1, 282.6), ^{140}La (1596.2, 487.0, 328.7), ^{69m}Zn (438.7), ^{187}W (479.5, 685.7), ^{82}Br (619.0, 776.5, 554.2), ^{76}As (559.1, 657.0), ^{122}Sb (563.9), ^{72}Ga (834, 630), ^{24}Na (1368.6), and ^{42}K (1524.7). Data with unsatisfactory accuracy and precision were collected for uranium via the daughter ^{239}Np (228.1, 277.9).

The samples, with their standards, that had been irradiated for 2 hours were allowed to decay for 30 days, after which the activities due to long-lived isotopes were counted in a 30,000 to 50,000 second counting interval and the following elements were determined: ^{141}Ce (145.4 keV), ^{182}Ta (1221.4, 222.1), ^{169}Yb (177.0, 197.9), ^{131}Ba (216.0, 496.3), Th via the daughter ^{233}Pa (311.9), ^{51}Cr (320.0), ^{181}Hf (482.0), ^{85}Sr (514.0), ^{134}Cs (795.8, 596.3), ^{124}Sb (1691.0), ^{152}Eu (1408.1, 779.1, 1086.0), Ni via ^{58}Co from the ^{58}Ni (n,p) reaction (810.8), ^{160}Tb (879.3), ^{46}Sc (889.2, 1120.5), ^{86}Rb (1078), ^{59}Fe (1099.3, 1291.6) and Fe via ^{54}Mn from the ^{54}Fe (n,p) reaction (824.8), ^{65}Zn (1115.5), and ^{60}Co (1173.2, 1332.4). The data collected for ^{75}Se (264.6, 279.5) were unsatisfactory in accuracy and precision.

The γ-ray spectrometer system used consists of a 55-cm^3 coaxial Ge (Li) detector coupled with a 4096-channel analyzer and a magnetic tape unit. The detector has an efficiency rating of 10.1 percent, a resolution of 2.2 keV (FWHM) at 1332 keV, and a peak/compton ratio of 30.5 at that energy. The data were analyzed by computer in which a modified Gamanal (P. K. Hopke, personal communication) program was used that fits the peaks with gaussian and exponential functions and smoothed background functions. [These data are not included in tables 2 and 3 but will be available from the Illinois State Geological Survey.]

Vertical Distribution

In the Chain of Lakes copper, lead, and zinc increase in abundance upward in the top 20 to 50 centimeters (8 to 20 inches) of most cores. Zirconium and nickel also show upward increases in two or more cores. Other elements that increase in the surface sample of at least one core include molybdenum, boron, cobalt, vanadium, and manganese. The upward increase in trace elements

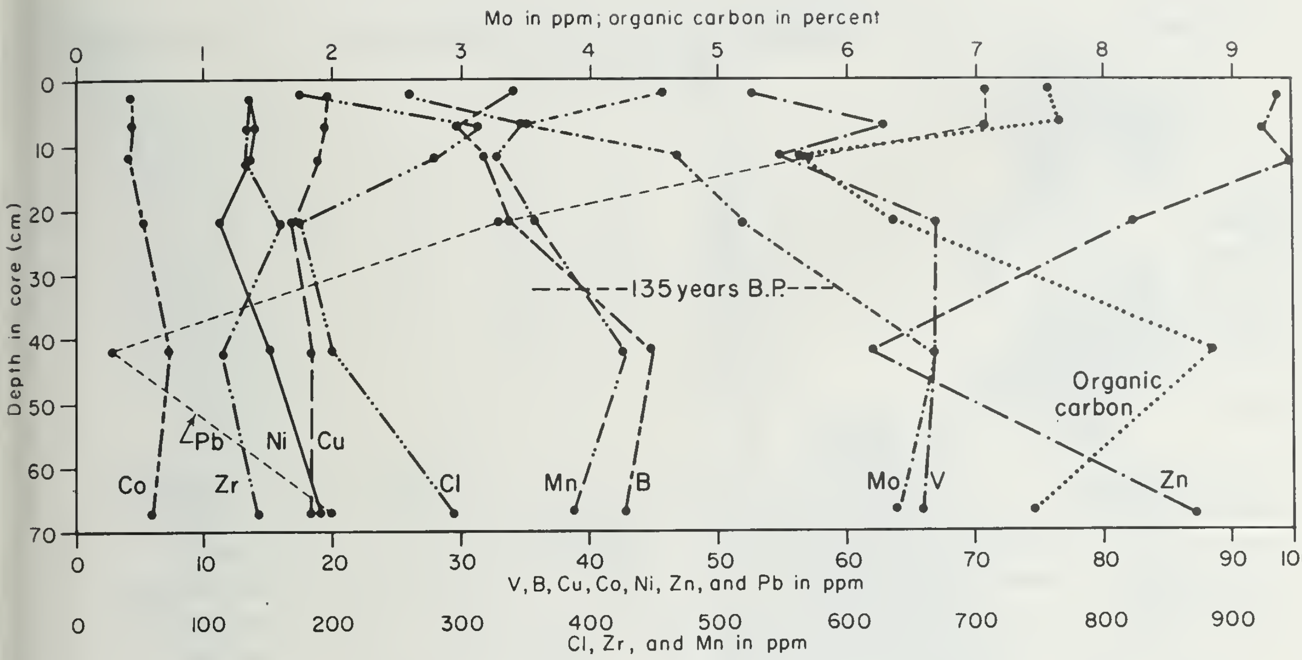

Figure 7. Depth profile for core 29B from Channel Lake

is most clearly seen in cores from the algal silts in the center of the deeper lakes where sedimentation has been slow and continuous (figures 4, 5, 6, and 7). Lead shows the greatest and most consistent increase. Background levels of lead in older sediments is about 20 ppm but increases to an average of 60 ppm at the top of the cores. In each of the three cores on which pollen data were determined, the increase in lead begins above the base of the *Ambrosia* horizon, that is, in sediment deposited after 1840. As most lead is believed to reach the lake environment through the atmosphere from automobiles burning leaded gasoline, this increase in lead probably has taken place within the past 50 to 70 years.

Lead values as high as 442 ppm were found in muck dredged from a boat channel occupied by a marina off Pistakee Lake. Some of the lead may come from gasoline spills or other activities associated with watercraft. One value exceeding 700 ppm recorded from Grass Lake was believed due to the presence of lead from lead shot used in duck hunting.

Areal Distribution and Sediment Type

In addition to the vertical variations within a single core mentioned previously, the geochemical content of the sediments varies from lake to lake and from sediment type to sediment type.

Among the major sediment components, aluminum, iron, silicon, and potassium vary with the proportion of quartz sand, silt, and clay minerals in the sediment. The calcium content of the sediment is proportional to the amount of shells or marl present. The sulfur and nitrogen contents increase with increasing organic content. The highest phosphorus content is in the muck sediments filling dredged channels.

Trace-element distribution in the different types of lake sediment also varies (table 2). In the surface samples, the highest concentrations of vanadium, boron, copper, nickel, lead, and zinc occur in the muck that fills dredged channels. The algal silts in the deep-water

Table 7. Mean Trace-Element* Concentrations of Sediment in the Various Lakes in the Fox Chain of Lakes

(Surface samples only)

Lake	*Number of samples*	*V*	*B*	*Cu*	*Co*	*Ni*	*Be*	*Mo*	*Ge*	*Zr*	*Pb*	*Zn*
Pistakee Lake	6	<30	13	14.8	<3.7	30.5	<1.2	<3.8	<5.3	54	45	63.4
Nippersink Lake	2	36	21	25.6	<3.8	30.4	<1	<1.3	<3	116	34	98.9
Fox Lake	10	31	21	19.8	<3.6	20.7	<1	<2.9	<4	72	37	81.7
Grass Lake	4	39	17	20.0	<6.9	28.6	<1	<2.5	<3	98	35	86.5
Upper lakes combined (Channel, Catherine, Marie, Petite, Bluff)	8	66	31	23.0	<4.7	19.7	<1.5	<2.7	<3	126	71	118.9

*Elements expressed in parts per million

basins contain high concentrations of these elements and also the highest levels of zirconium, molybdenum, and beryllium. Marls contain the highest amounts of cobalt and germanium and high values of molybdenum, but they have the lowest concentrations of most other trace elements, including lead and zinc. The muck contains the highest total average content of trace elements in the lake system, and the sample with the highest total concentration of combined trace elements (1090 ppm) is the muck sample from a marina in a dredged channel off Pistakee Lake.

The upper lakes (Channel, Catherine, Marie, Bluff, and Petite) have higher average concentrations of zirconium, lead, zinc, vanadium, and boron than the other lakes (table 7 and figures 8 and 9). Copper is most abundant in Nippersink Lake; nickel is most abundant in Pistakee, high in Nippersink and Grass Lakes, but low in Fox and the upper lakes. The areal distribution of nickel, therefore, appears as the inverse of the distribution of lead (figure 10).

It is somewhat puzzling that concentrations of most trace elements are higher in the upper lakes than in the lower lakes. The upper lakes are deeper and appear, on superficial examination, to be cleaner than the shallower lower lakes. The samples from the upper lakes, however, are mostly from algal silts that contain higher average concentrations everywhere in the lake system than do the shelly silts more common in the lower lakes. Also, current studies show that water currents are moving from Grass Lake into Lake Marie and then into Channel Lake. This northward movement of water may move sediment out of Grass Lake, and the sedimentary material carried in by the Fox River may be concentrating in the upper lakes rather than being carried through the lake system and out the Fox River outlet.

Organic Carbon

The organic carbon content of the algal silt in all cores shows a decrease of about 1 percent between depths of 12 and 52 centimeters (5 and 20 inches) (figures 4, 5, 6, and 7). This dip in organic carbon may represent a system-wide change in the lake chain that has taken place within the historical past. The decrease may be related to the increase in water depth and wave action that occurred with the damming of the Fox River at McHenry. These changes could have resulted in a temporary lower production of organic matter.

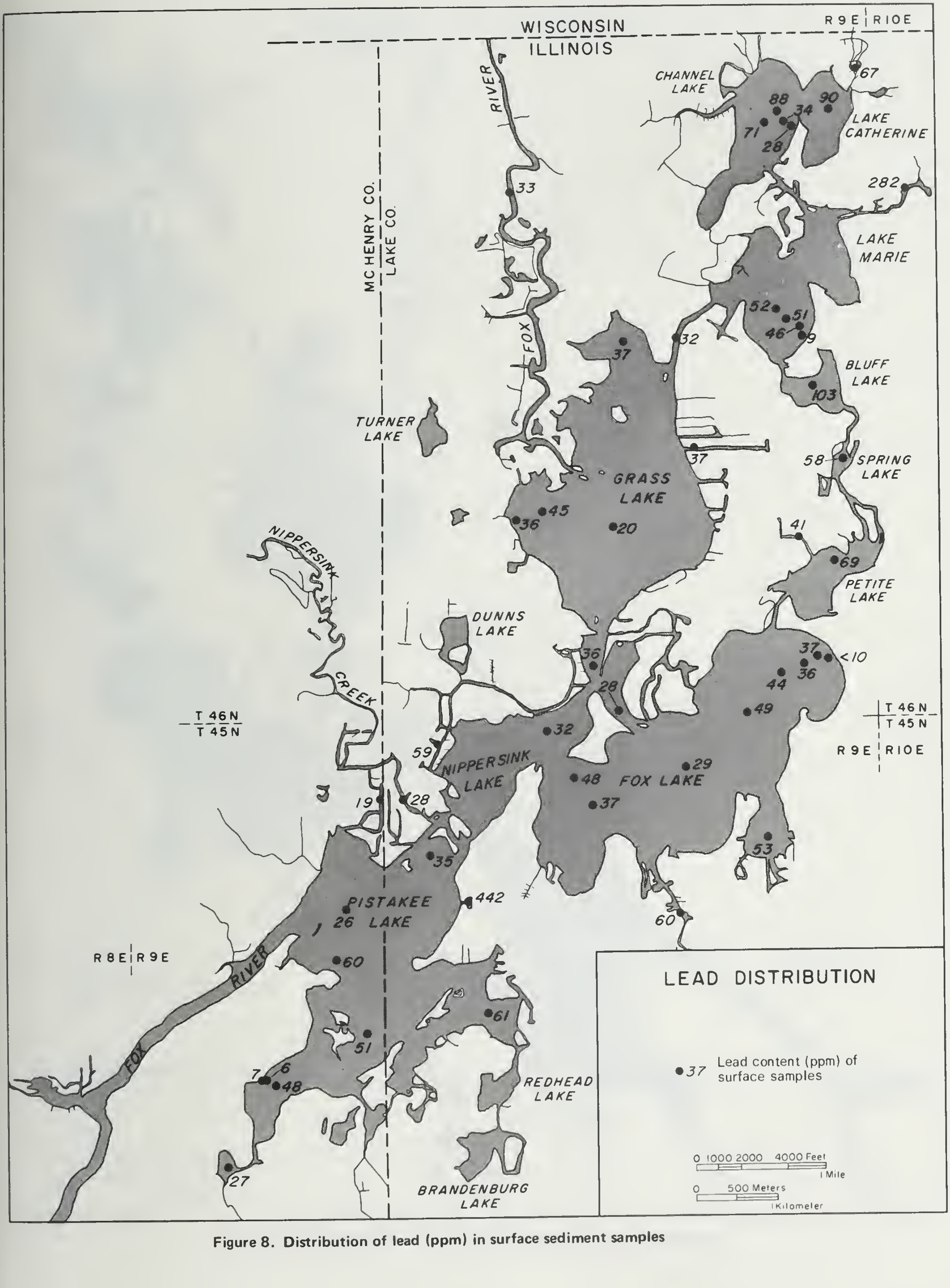

Figure 8. Distribution of lead (ppm) in surface sediment samples

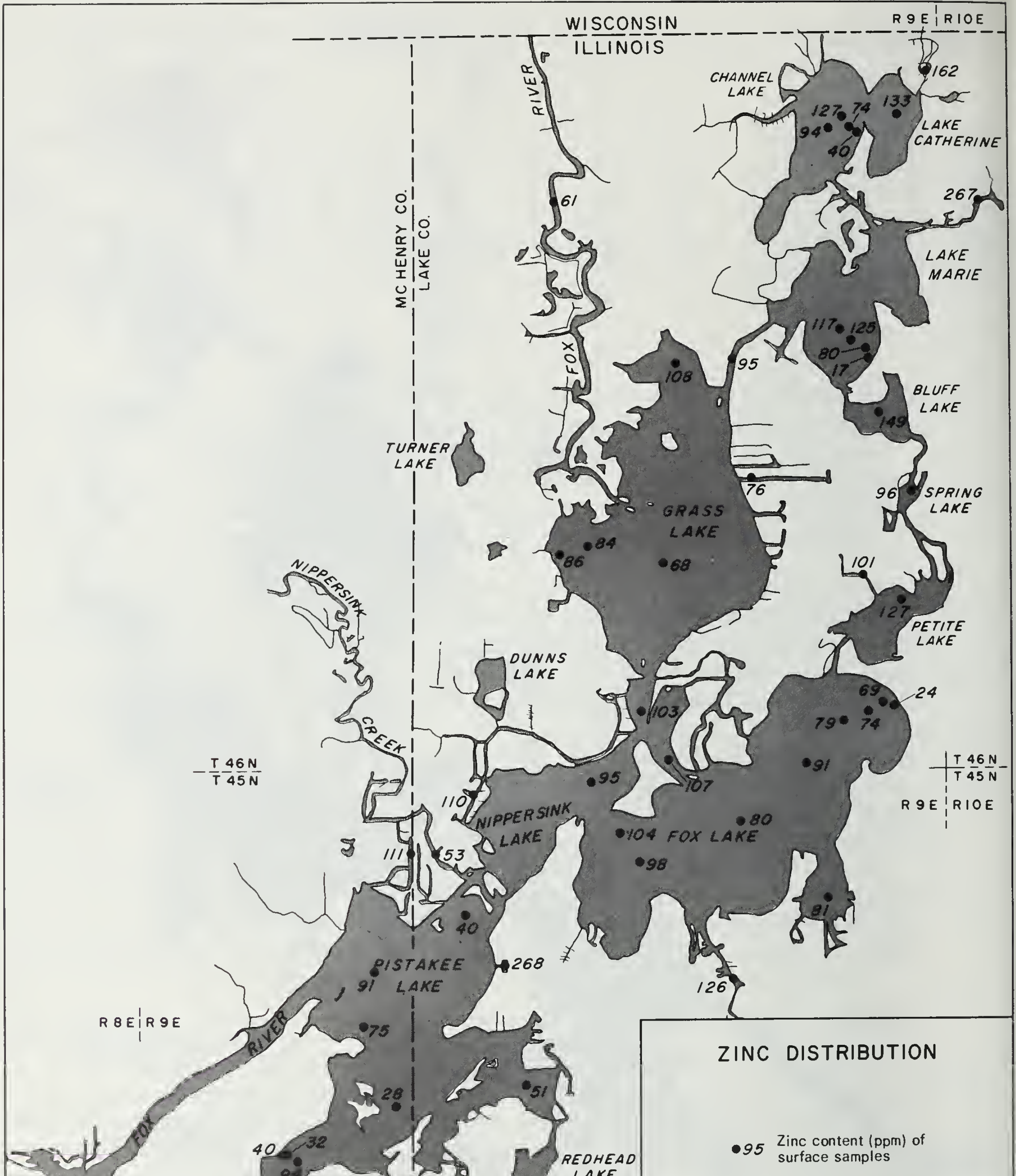

Figure 9. Distribution of zinc (ppm) in surface sediment samples

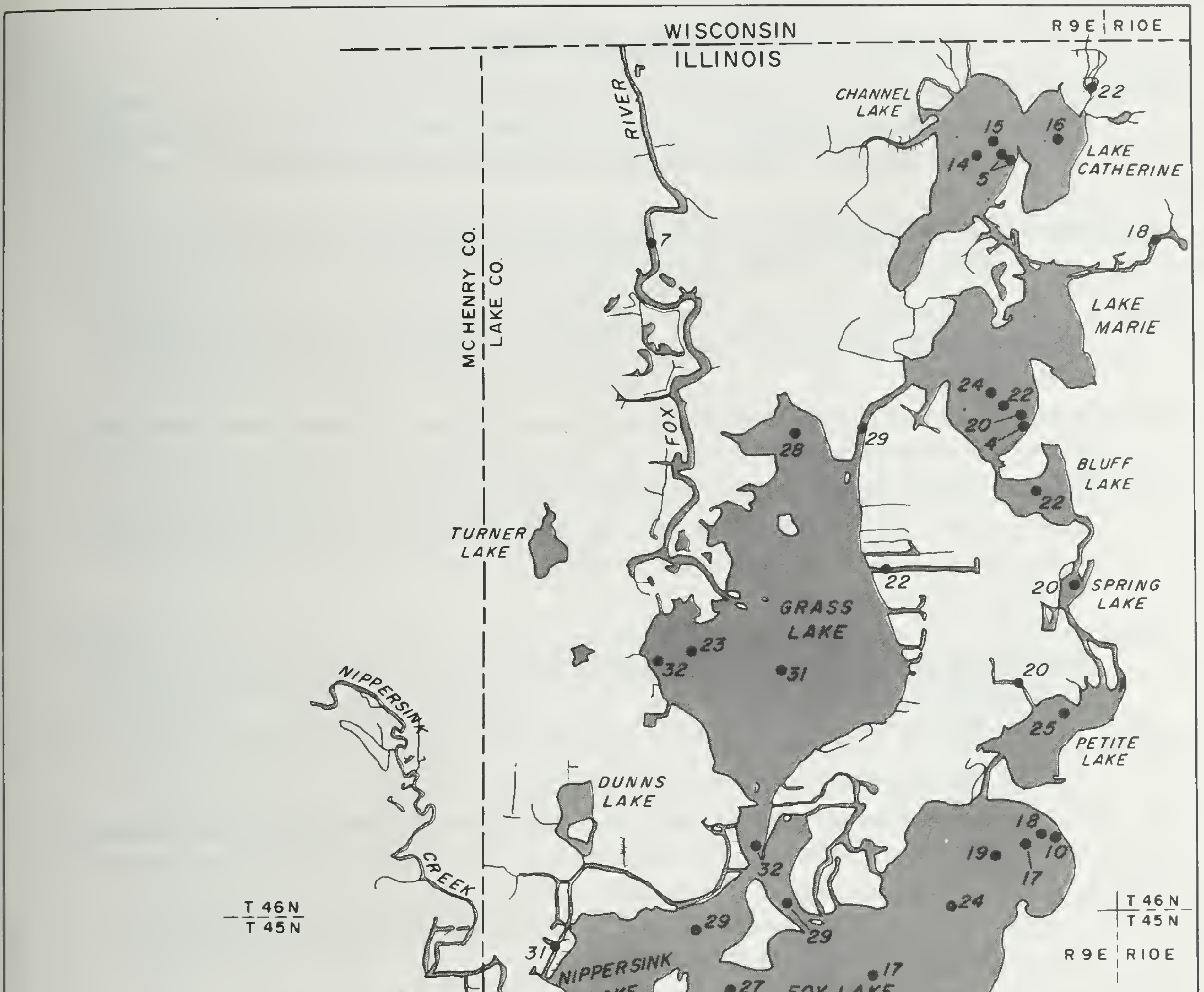

Figure 10. Distribution of nickel (ppm) in surface sediment samples

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Part 2. Hydraulics and Hydrology of the Lakes

BACKGROUND DATA AND FIELD DATA COLLECTION

The Hydrology Section of the Illinois State Water Survey investigated the hydrologic and hydraulic aspects of the Fox Chain of Lakes. The major areas of concern were:

1) Water budget including all inflows and outflows
2) Scour and deposition patterns in the lakes
3) Circulation patterns in the lakes and the interflow between the lakes
4) Theoretical detention times in all the lakes

Field data related to these major areas of concern were collected from December 1974 to November 1975, and these were supplemented by data available from other sources. However, in order to get a feel of the representativeness of this information, the data were compared with long-term variations of certain parameters.

Climate

The climatological parameters that were compared are wind velocity and direction, precipitation, evaporation, and temperature. Long-term climatological data in the vicinity of the Chain of Lakes were available only from the National Weather Service station at Chicago.

Figure 11 shows the wind velocity variation from July 1974 through June 1975. Average daily wind velocities remained in the vicinity of 8 to 10 miles per hour (mph) and the wind generally blew from the southwest.

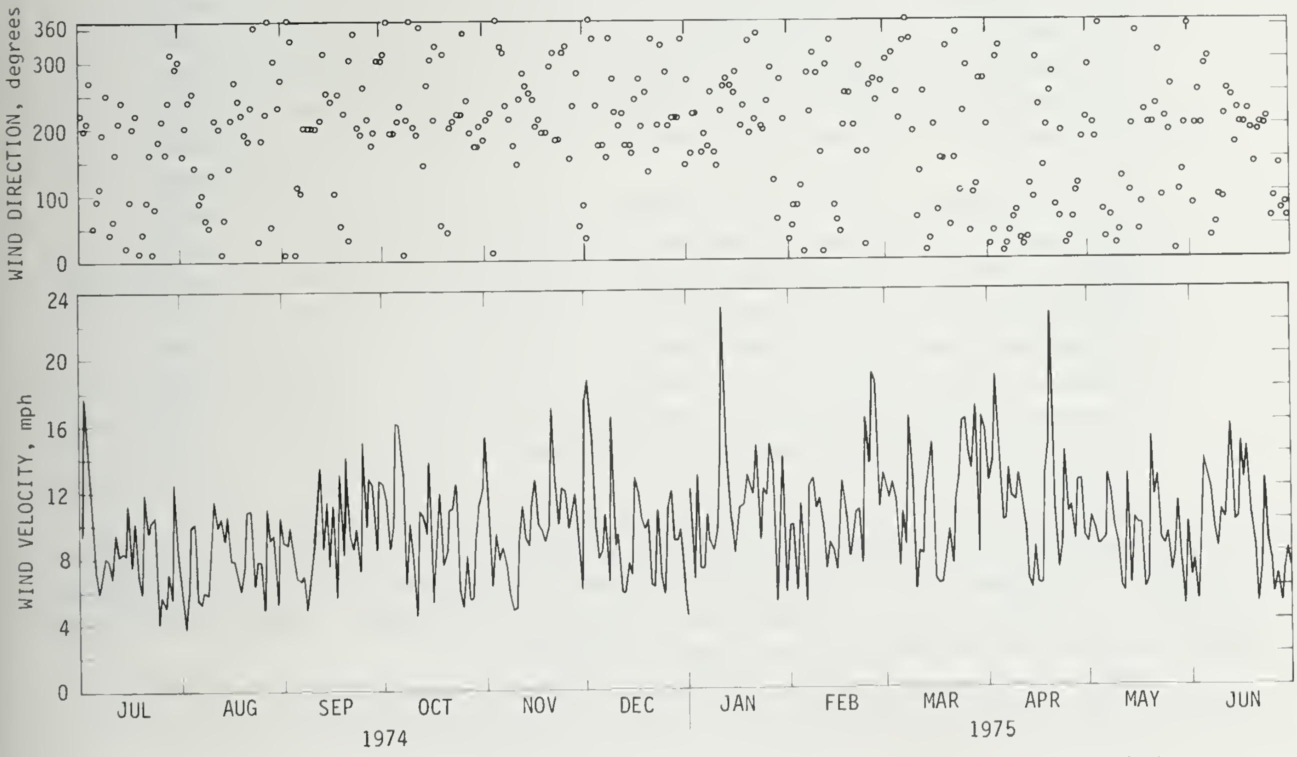


Figure 11. Wind velocity and direction, July 19, 1974 through June 19, 1975 *(Data from Chicago Weather Station)*

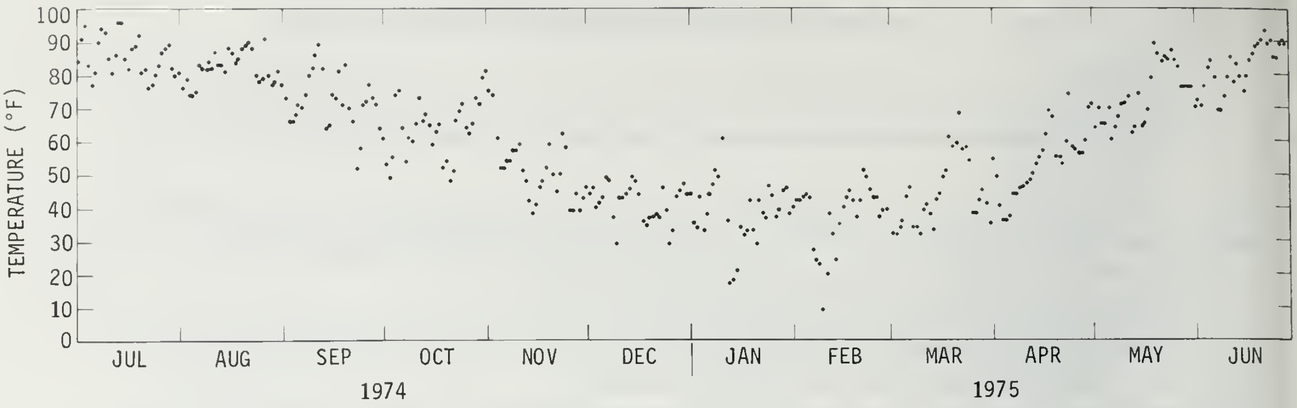


Figure 12. Temperature variation from July 1974 through June 1975 *(Data from Chicago Weather Station)*

Table 8. Comparison of Long-Term and Short-Term Values of Climatological Parameters

	Wind velocity (mph)		*Predominant wind*	*Temperature (°F)*			*Evaporation*	*Precipitation*
	Max	*Avg*	*direction*	*Max*	*Min*	*Avg*	*(inches)*	*(inches)*
November 1974	26	9.7	SW	78	22	40.9	0.66	2.82
November 1960–1974	36	10.6	SW	64	20	41.4	0.85	2.19
December 1974	26	9.3	SW	47	11	31.2	0.24	2.35
December 1960–1974	33	11.4	SW	58	0	26.6	0.36	2.76
January 1975	42	11.0	SW	60	2	27.9	0.33	3.68
January 1960–1974	33	12.0	WSW	54	-8	22.9	0.32	1.93
February 1975	35	10.7	W	51	-6	26.9	0.55	2.29
February 1960–1974	35	12.0	W	54	0	26.9	0.58	1.43
March 1975	31	11.3	NW	74	12	34.2	1.56	2.44
March 1960–1974	37	12.4	NW	72	13	37.7	1.65	2.69
April 1975	35	11.1	NE	76	16	43.5	2.44	7.84
April 1960–1974	39	12.5	variable	76	29	50.0	2.75	4.08
May 1975	35	9.1	E	94	39	63.0	1.39	5.31
May 1960–1974	34	11.1	SW	88	35	60.0	4.10	3.01
June 1975	33	9.6	S	92	49	72.1	5.49	4.63
June 1960–1974	36	10.1	SW	95	48	70.5	4.70	4.43
July 1975	19	8.0	SW	93	52	76.1	5.95	1.53
July 1960–1974	34	9.0	SW	95	53	74.4	5.80	4.30
August 1975	23	8.8	S	94	60	76.4	4.49	5.51
August 1960–1974	31	8.8	SW	94	53	73.3	4.55	2.68
September 1975	29	8.9	SW	86	39	61.4	3.06	1.09
September 1960–1974	30	9.4	variable	91	42	66.4	3.00	3.90
October 1975	27	10.6	S	89	33	56.6	1.88	2.26
October 1960–1974	29	9.5	SW	84	31	55.7	2.10	2.25

Figure 12 shows the variations of the average daily temperatures from July 1974 to June 1975. A cyclic variation in the temperature range is evident with the maximum in the months of May through August and minimum in the months of December through February. Short monthly cyclic variations are also evident in this figure.

Table 8 compares the long-term (1960–1974) monthly average values of various climatological parameters with monthly average values for November 1974 through October

1975. This table shows that the average wind velocity and direction for the year 1975 are generally comparable with the long-term wind data. Both short- and long-term temperatures also compare favorably, and evaporation in 1975 basically remained the same as the long-term average. The precipitation data indicate that 1975 was slightly wetter than the long-term average precipitation.

Long-Term Stage Records

The U.S. Geological Survey and the Illinois Division of Water Resources (DOWR) maintain recording and nonrecording stage gages in and around the Chain of Lakes (figure 13). Long-term stage records from 1959 to 1975 were obtained from DOWR and an analysis was made to check any systematic variations of the lake levels between these stage records at various locations. It must be pointed out that since most of these gages are non-recording types, the stages that were analyzed were not collected at the same time of day.

It was thought that wind might have some effect on the variation of the water levels at various parts of these lakes. All the lakes are oriented in more or less southerly or southwesterly directions. The long-term wind analysis (figure 11 and table 8) indicates that the wind normally blows from the south or southwest. This predominant wind can pile up water on the eastern shore of the lakes with an associated lowering of water level at the western shore. This phenomenon is termed *wind tide.*

In order to investigate the variations in water levels between different stages for strong winds from the southwest, a number of plots were prepared comparing stages at McHenry Lock and Dam with stages at Nippersink Lake, Columbia Bay in Fox Lake, and Channel Lake. Typical plots are included in this report. In general, there are some variations in the stages with or without wind.

Figures 14, 15, and 16 show the stage variations between McHenry Lock and Dam and Nippersink Lake, Columbia Bay, and Channel Lake, respectively. These figures show the variations for both light winds (2 to 5 mph) and strong (10 to 30 mph) southwest winds. Table 9 was prepared on the basis of these figures and shows the maximum differences between various stations for light and strong winds. Most of the time, a maximum of about 0.5 foot variation can be attributed to the wind effect. However, this is a maximum variation, not an average value.

Figure 17 shows the stage variation between Channel Lake and Nippersink Lake for strong SW winds. The average variation is about 0.3 foot with a maximum value of 0.55 foot. Similarly figure 18 shows the stage variation between Columbia Bay in Fox Lake and Nippersink Lake for strong W, WSW, and SW winds. The effect of a SW wind on Fox Lake should be predominant because it is located exactly in the SW direction. However, on the average the variation between these stations is in the order of 0.1 foot with a maximum variation of about 0.4 foot. Therefore, it appears that either the wind tide is not significant or the data on stages were not collected simultaneously from various gages when the wind was blowing hard from the SW.

A sample computation was made to estimate the amount of wind tide in Fox Lake for some hypothetical wind conditions blowing from the SW (table 10). Many researchers have studied this phenomenon as reported by Saville et al. (1962) and the following relation is generally accepted as valid to estimate wind tide

$$S = (K V_z^2 F_e \cos \alpha)/D$$

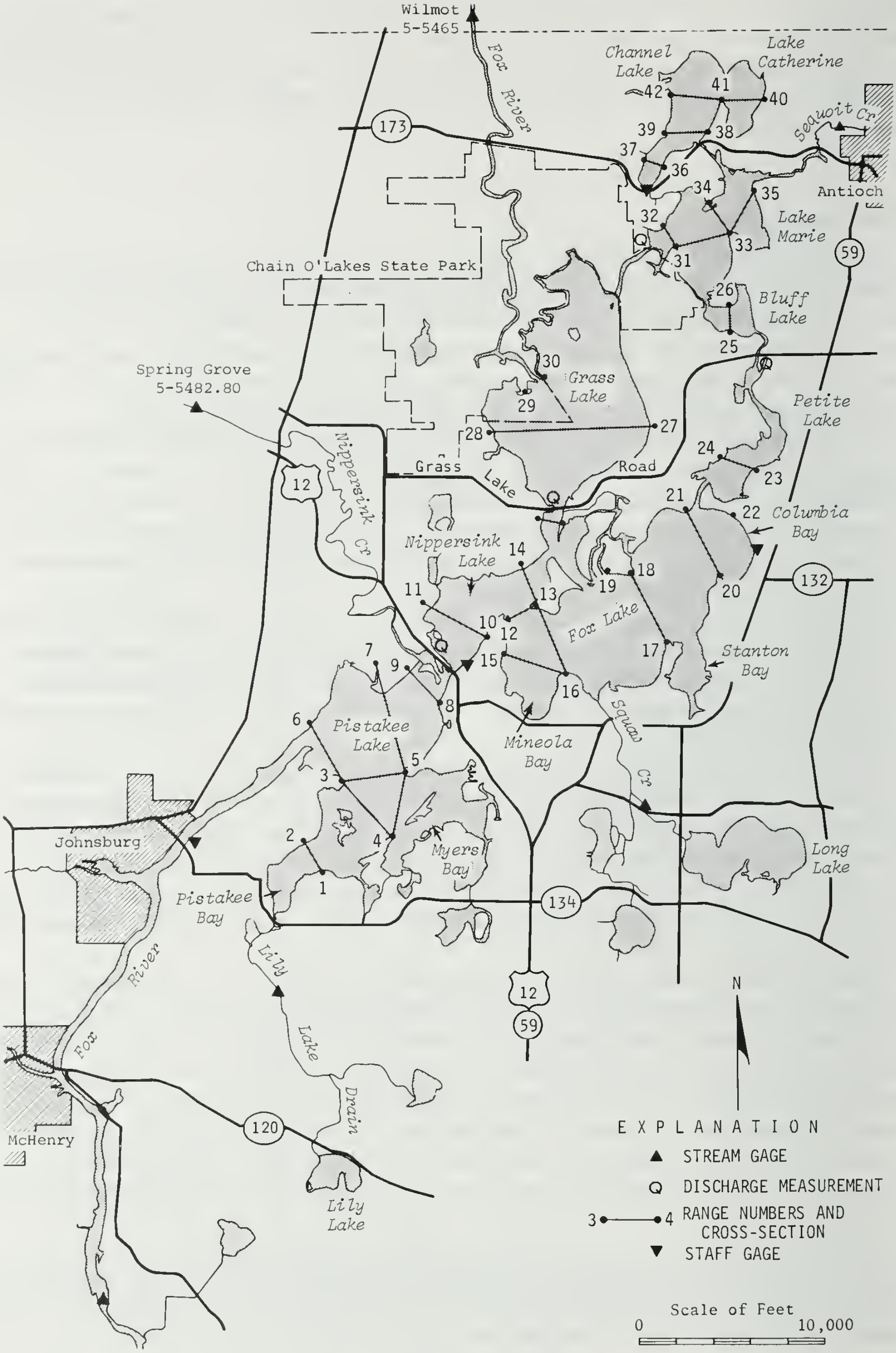


Figure 13. Fox Chain of Lakes

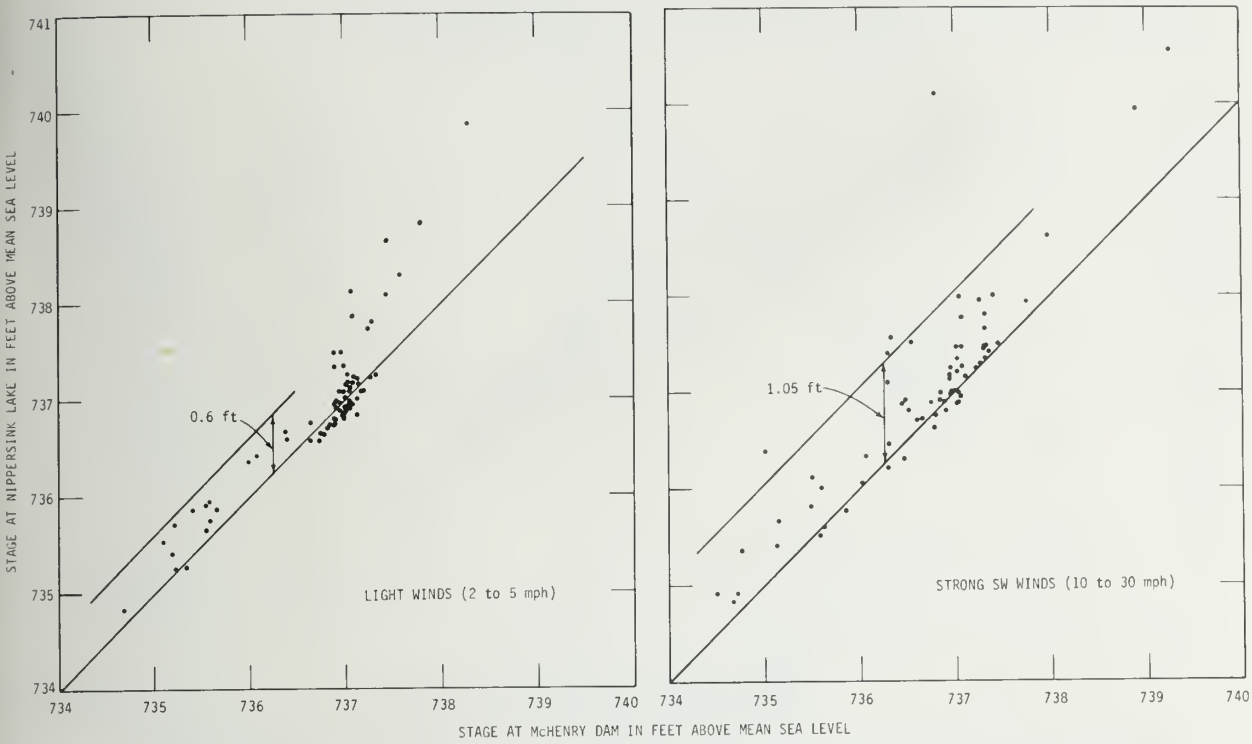


Figure 14. Stage variations between Nippersink Lake and McHenry Lock and Dam for different wind conditions

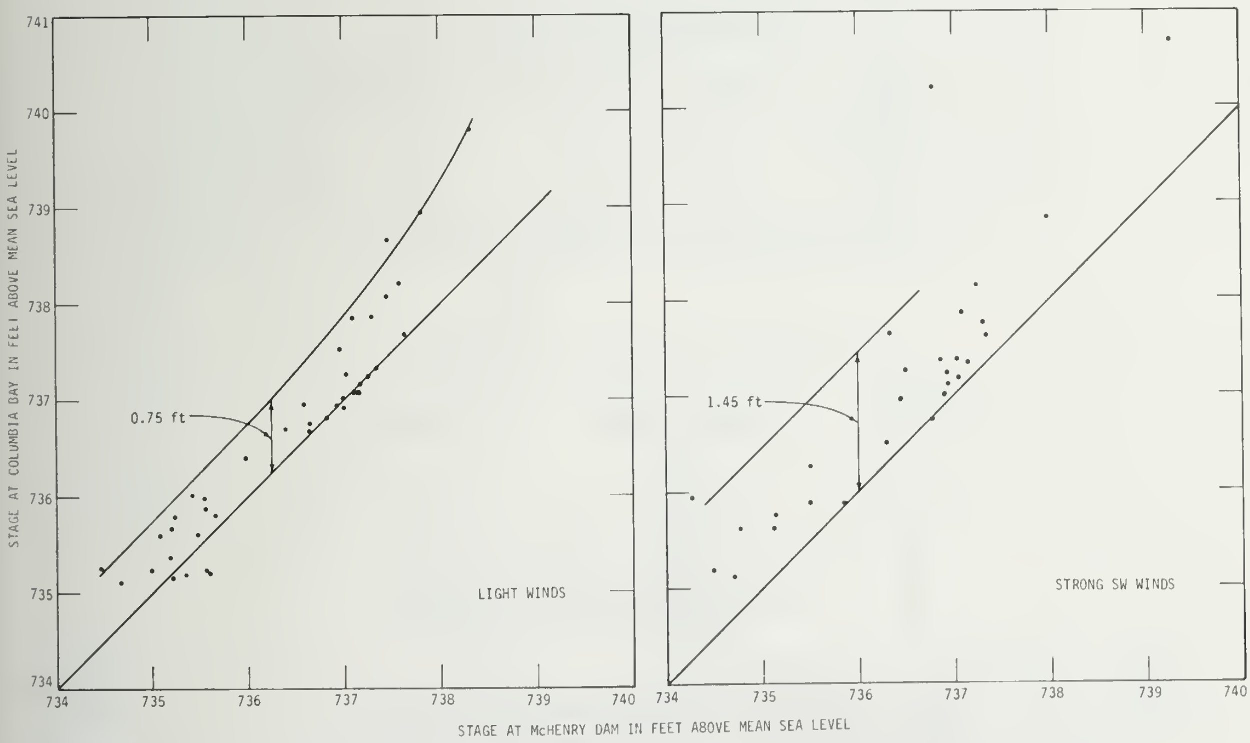


Figure 15. Stage variations between Columbia Bay and McHenry Lock and Dam for different wind conditions

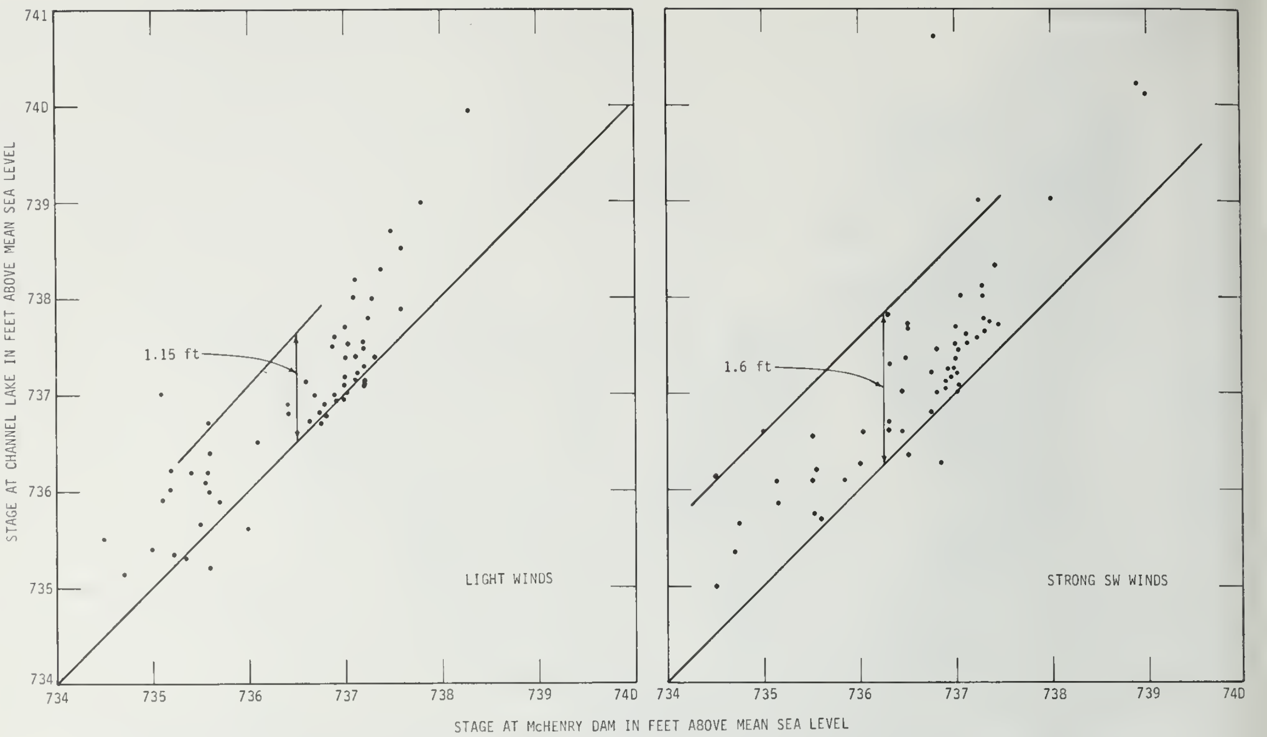


Figure 16. Stage variations between Channel Lake and McHenry Lock and Dam for different wind conditions

Table 9. Differences in Water Surface Elevations*

Wind condition	*Maximum difference in elevation (in feet) above McHenry Dam* to Nippersink	to Columbia Bay	to Channel Lake
Light or no wind	0.60	0.75	1.15
Strong SW wind	1.05	1.45	1.60

*Normal pool level 736.5 ft above msl at McHenry Lock and Dam; data for 1959-1975

Table 10. Wind Tide in Fox Lake with SW Wind

Wind speed, V_z (mph)	*Wind tide, S, in feet, Fox Lake only**	*Wind tide, S, in feet, Nippersink-Fox Lake***
5	0.009	0.010
10	0.037	0.044
15	0.082	0.098
20	0.148	0.176
30	0.330	0.393
40	0.600	0.715
50	0.900	1.07

*Fetch = 2.88 miles for Fox Lake

**Fetch = 3.43 miles as measured from a point near Riverside Island in Nippersink Lake to the shore of Columbia Bay in Fox Lake

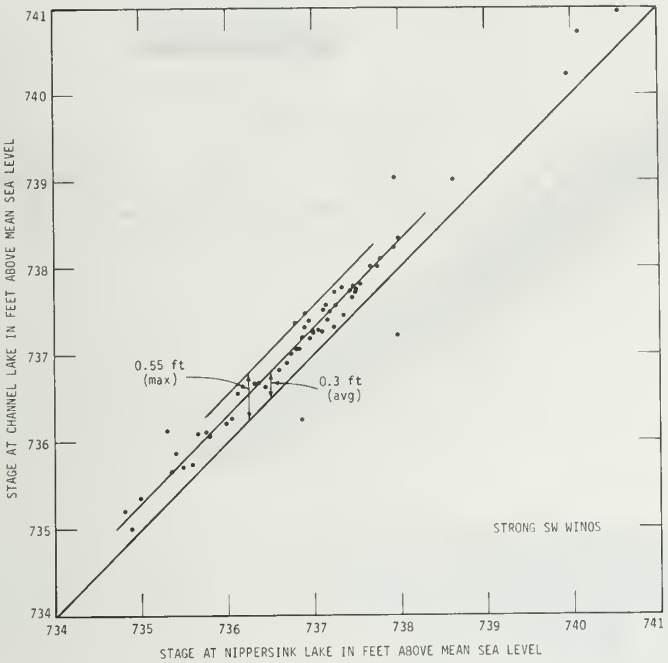


Figure 17. Stage variations between Channel Lake and Nippersink Lake for strong southwest winds

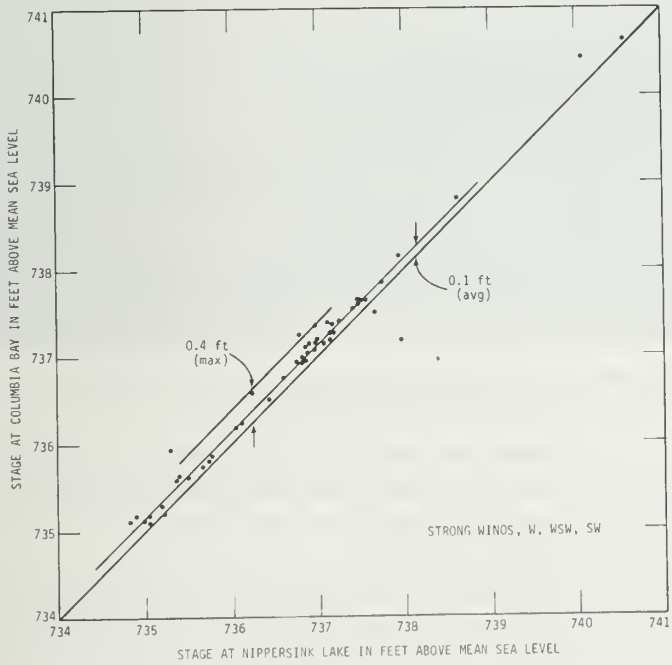


Figure 18. Stage variations between Columbia Bay and Nippersink Lake for strong winds

where S is the wind tide, K is a coefficient, V_z is the wind velocity, F_e is the fetch or length of water surface, α is the wind angle with the main fetch length, and D is the average depth of water in the lake. The value of K is taken to be 1/1400 (Saville et al., 1962) with F_e in miles, V_z in mph, cos α equal to 1.0, and D equal to 5.6 feet for Fox Lake (from figure 28).

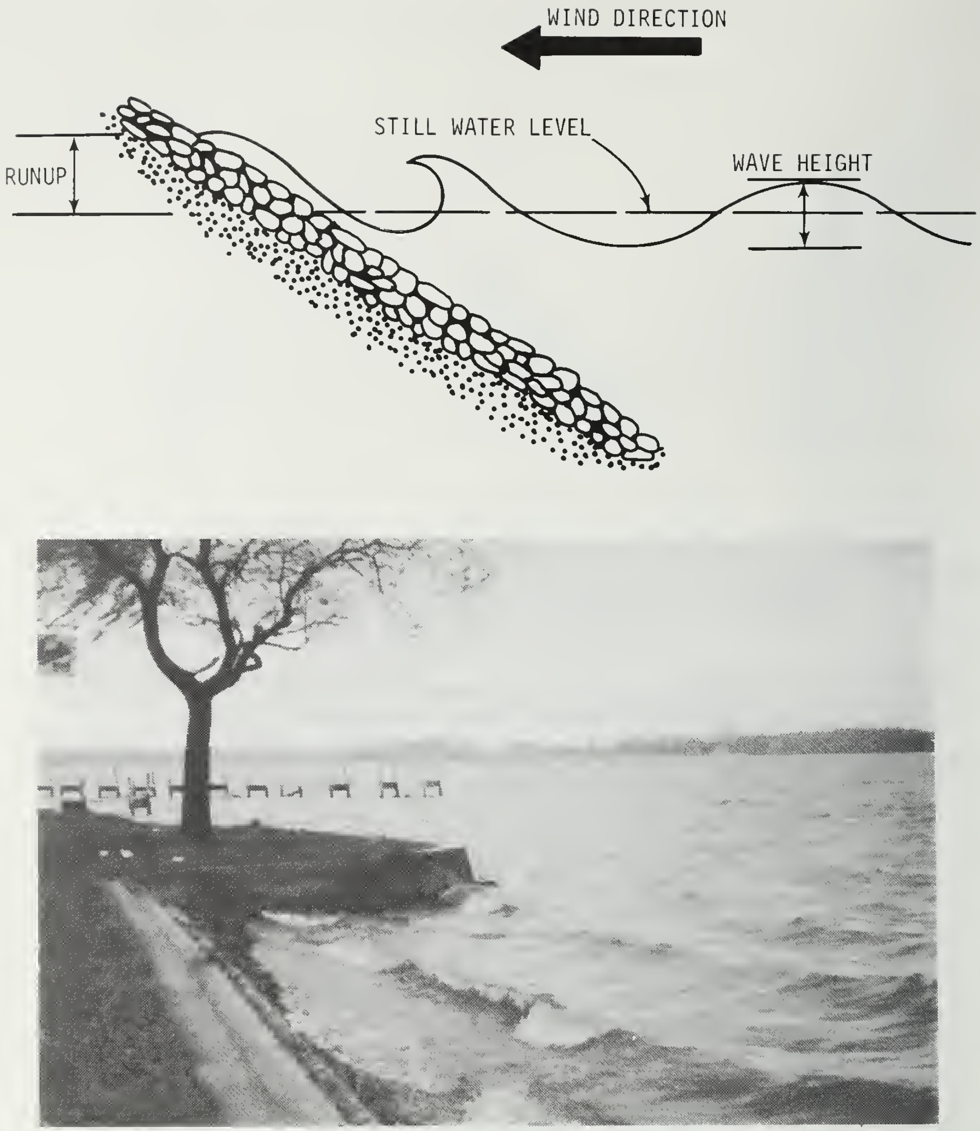


Figure 19. Sketch of a wave breaking on a lake shore and waves breaking at Eagle Point Park on a windy day

Thus is appears that, for a sustained wind of 50 mph from the SW, a maximum wind tide of 1.07 feet is possible in the Columbia Bay area of Fox Lake. However, in order for a wind tide of 1.07 feet to occur, the wind must be blowing continuously for some time from the SW in line with the maximum fetch of the lake.

Another phenomenon which might give the appearance of an increased water depth on the eastern shore of Fox Lake with wind blowing from the SW is termed *wave runup.* When a wave breaks up on a high shore or sea wall, it rushes up the shore and breaks above the normal water level. The water then travels back down the shore and returns to the lake. With a sustained wind, this breaking of waves is continuous, and at a glance will look like an increased depth of water on the leeward side of the lake. Figure 19 shows a sketch of a wave breaking up on a shore and a picture of breaking waves at Eagle Point Park on one of the many windy days.

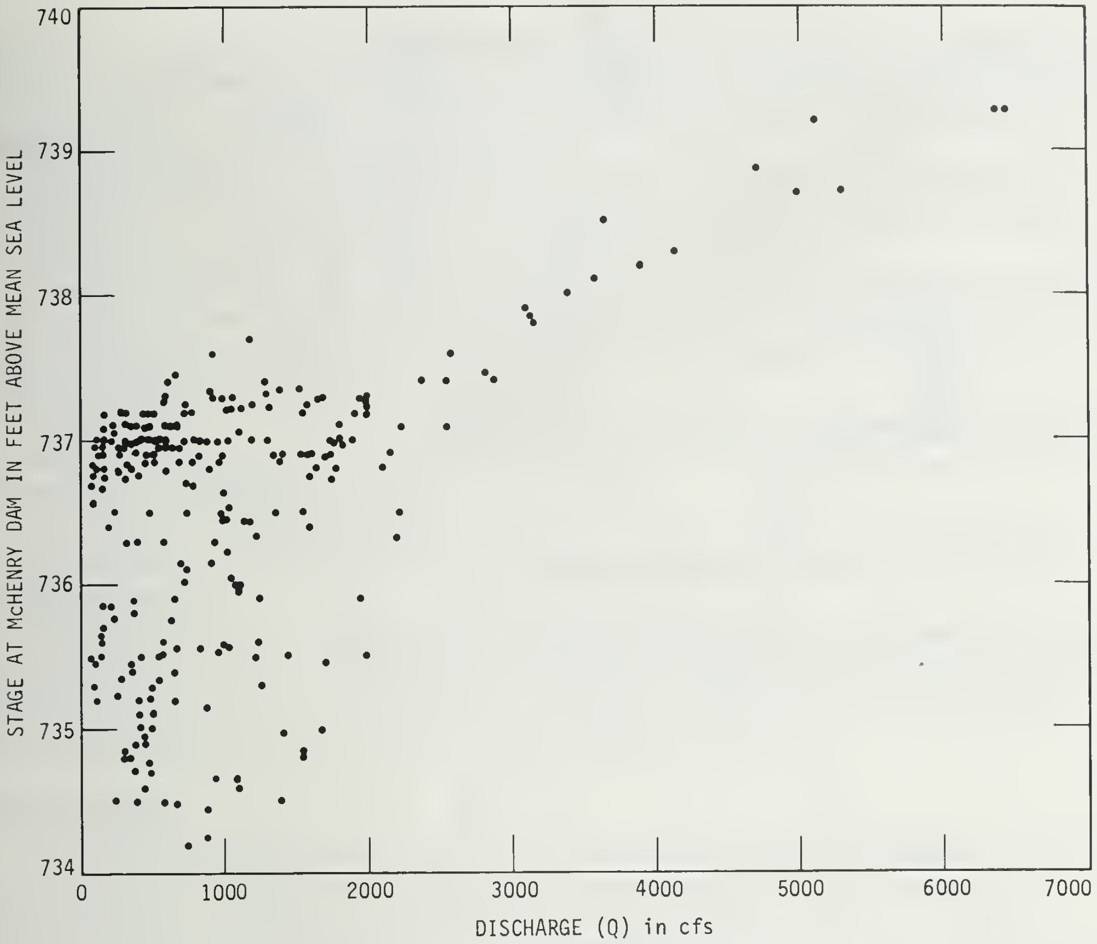


Figure 20. Stage versus discharge at McHenry Dam (1959-1974)

According to Hedar (1953) the *wave runup* can be as much as 1.25 times the wave height when the ratio of wave length to the wave height is about 20. Wave heights in any enclosed body of water, such as lakes and ponds, can be computed by the method presented by Bhowmik (1976).

Figure 20 shows the stage versus discharge relationship at McHenry Lock and Dam. Above a stage of about 737.5 feet above msl, the gates at McHenry Dam have little or no control of the total quantity of flow that will pass below the dam.

Long-term stages from all the Chain of Lakes gages were also statistically analyzed to determine cyclic variations in the stages. Auto-correlation analysis indicated cyclic variations of 12 months, which also contain 3-, 6-, and 9-month cyclic variations. This is natural, since all these lakes are basically fed by streams and their water levels fluctuate with inflows which have a basic cyclic variation of 1 year.

Field Data Collection

Field Surveys

Extensive field data collected in connection with this investigation required some precise surveying in the Chain of Lakes region. Forty-two permanent concrete monuments

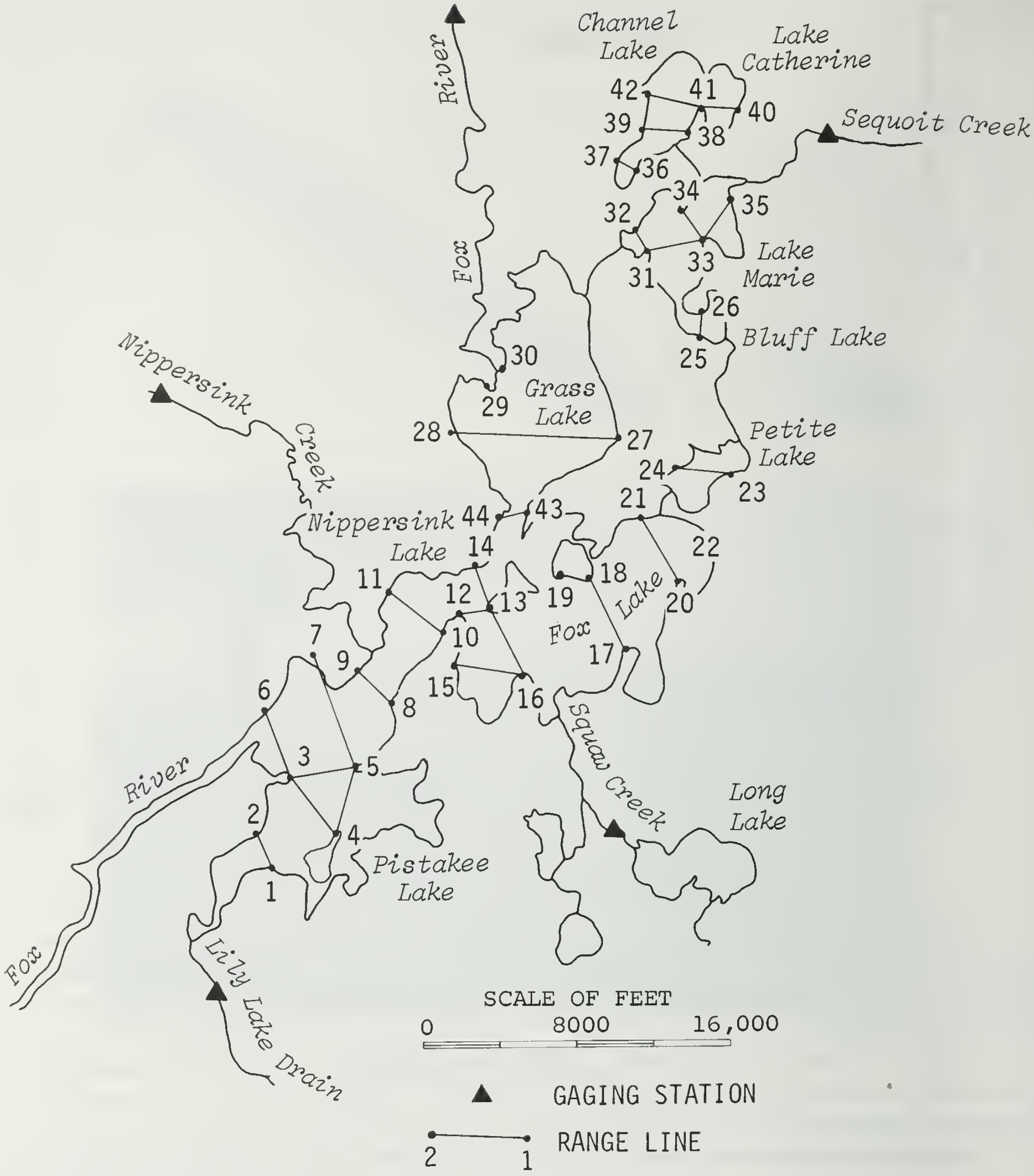


Figure 21. Locations of depth measurement monuments

and a number of semi-permanent monuments were installed around the lake shores (figure 21). A line joining any two monuments indicates that the 1975 lake bed elevations were determined at those locations. The station 29 monument could not be installed since this location is marsh.

Horizontal Control. The horizontal control consisted of an electronic traverse, run to second-order specifications, using T2 theodolites and a Laser Ranger distance-measuring device. The primary control stations for the project were USGS triangulation stations located in the Chain of Lakes area. The total control network consisted of 106 stations and 166 observed lines.

In cases where a number of stations surrounded a lake, all possible intervisible lines were observed and measured, and all measured lines were used in the final adjustment procedures.

The closures of the various lines and loops ranged from 1 part in 16,100 to 1 part in 569,400, with an average of 1 part in 78,600.

Whenever possible, at least one prominent object was pointed as an azimuthal mark at each station. In addition, coordinates were determined by intersection on 10 prominent structures (water tanks, radio masts, etc.) within and around the area.

Vertical Control. The vertical control consisted of lines of spirit leveling for which the '3 wire' method was used, with automatic and prism levels, and 'invar' precise rods. A number of water crossings were required, and these were accomplished by standard 'river crossing' techniques with multiple observations.

The project was run on mean sea level datum as determined from nine USGS benchmarks distributed about the area. The entire network was adjusted as a whole, holding fixed all of the undisturbed USGS benchmarks.

Although the USGS benchmarks were listed as being of third-order accuracy, nearly all of the benchmark to benchmark closures, as well as the loop closures, met second-order accuracy requirements.

In addition to determining elevations on all of the monuments, approximately 100 supplementary benchmarks were set at intervals along the level lines. Also, whenever possible, a reference benchmark was set near each monument, as a precaution against the monument being lost or inadvertently disturbed.

Depth Measurements

The 1975 lake bed elevations were determined along 26 cross sections as shown in figure 21. Depths were measured for a minimum of 5 points and a maximum of 10 points in each cross section. The end points of the cross section lines were the various concrete monuments set as part of the control survey. Individual soundings were located by lining the boat with a transit and reading the distance out with the Laser Ranger.

The lake bed measurements were made with a steel pipe rod, 20 feet in length, with a 4-inch diameter plate on the bottom and a sliding level target. Depths over 20 feet were measured on calm days, using a chain to extend the rod.

The three independent readings of the lake bed elevation taken at each sounding were: 1) depth from the water surface; 2) level reading from shore to the sounding rod target; and 3) vertical angles from shore to the top of the rod. The last two were corrected for curvature and refraction, and all three were averaged for a final lake bed elevation.

The lake bed character was tentatively determined by the feel of the rod on the bed, and by examination of the lake bed material on the boat anchors as they were pulled.

Inflows and Outflows

Basically the inflow and outflow data were gathered from established gaging station records. However, at the beginning of the project, it was observed that at least three small tributaries for which no inflow records were available enter the Chain of Lakes. Three temporary wire-weight gages were installed at the three tributaries, namely, Sequoit Creek, Squaw Creek, and Lily Lake Drain (figure 21). These three gages were read daily and the USGS developed rating curves at all three locations. In addition to these three gaging stations, records from permanent gaging stations of Wilmot, Wisconsin, on the Fox River and from Spring Grove on Nippersink Creek, as well as discharge records at McHenry Lock and Dam, were also utilized.

Interflow between Lakes

In order to understand the flow pattern and the general movement of water in all the lakes some qualitative and quantitative information regarding interflow between the lakes should be known. Interflow between Grass Lake and Lake Marie, flow from Bluff Lake to Petite Lake at Grass Lake Road Bridge, flow from Grass Lake to Fox and Nippersink Lakes at Grass Lake Road Bridge, and the flow from Nippersink Lake to Pistakee Lake under both bridge openings of Highway 12 were gaged in the months of December 1974 and May, July, and October of 1975. In addition to these gaging data, some qualitative information was obtained by using floats and vanes at some locations in November 1975.

During the latter part of the data collection period it was observed that a measurable amount of water was flowing under the east and west bridges of Highway 173 between Channel Lake and Lake Marie. On four occasions in October and November 1975, the flow under these bridges was estimated by the use of floats and cross-vanes.

Circulation Patterns

Interflow between lakes gives some indication of the general movement of water in all of the lakes. However, circulation patterns in some of the connecting areas were needed for a better understanding of the flow patterns of the lakes as a whole. Extensive data on circulation patterns were collected in 1975.

The average flow velocity within any one of the lakes is very small. To date, there is no commercial flow meter available that can measure the very small velocity in lakes. After considerable literature review, a method used by Shulman and Bryson (1961) to measure wind driven currents in Lake Mendota (in Wisconsin) was adopted. The method consists of dropping a cross-vane suspended by a nylon cord and a float at some location in the lake and then following the float by two theodolites from two fixed shore stations. Figure 22 shows a sketch of the float and cross vane arrangement. The depths of the vanes varied depending upon the flow depth in the lakes. Three or four drops were made at each location with vanes at different depths. This technique resulted in mapping the flow patterns at each selected location at all possible depths below the water surface. Simultaneous readings at some specified interval, usually 5 to 10 minutes, from two fixed shore stations were needed to map the direction and to compute the magnitude of the flow velocity for each drop of a float and vane. In order to test the cross-vane movement with the average velocity of the surrounding water, the cross-vanes with floats were calibrated at the Water Survey hydraulics laboratory in the 2-foot-wide and 60-foot-long flume. The correlation was excellent.

Figure 23 shows a sketch of the actual operation of determining the circulation patterns by this technique. At every predetermined interval of time, angles a and b were measured simultaneously. At the end of time t, angles a′ and b′ were measured and this procedure was repeated until sufficient data had been collected. Then the floats were moved to another location and the procedure was repeated. The base distance between 8 and 9 in figure 23 was determined by using an electronic distance-measuring instrument. A simple triangulation technique was needed to determine the actual location of the floats in the lake. Normally, three floats at different depths (12, 24, and 36 inches) were dropped and followed at the same time.

Figure 24a shows a float in the water. Sometimes a brightly painted table tennis ball was fixed on a thin rod on top of the float to make it easier to see against the reflections on the water surface. Figure 24b shows the location of Station 32 on the west shore of Lake Marie where the flow patterns from Grass Lake to Lake Marie were being tracked.

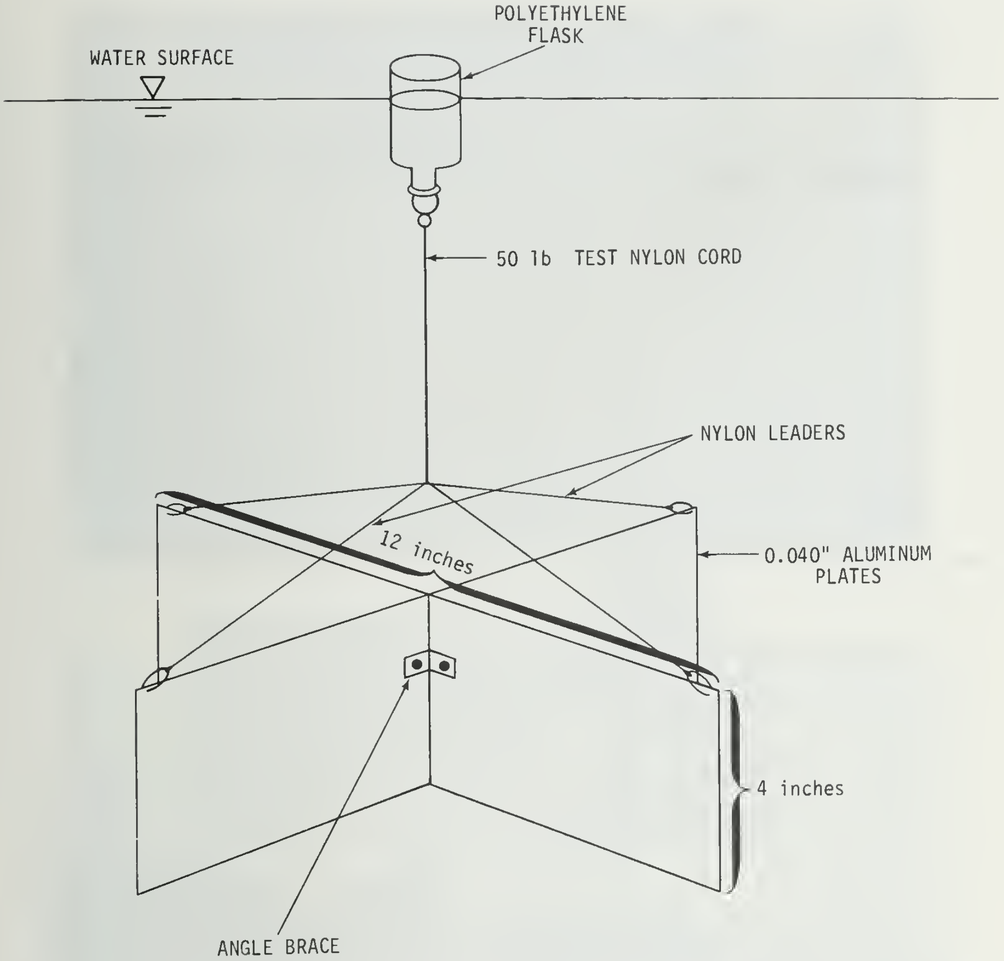


Figure 22. Float and cross-vane used to measure circulation patterns

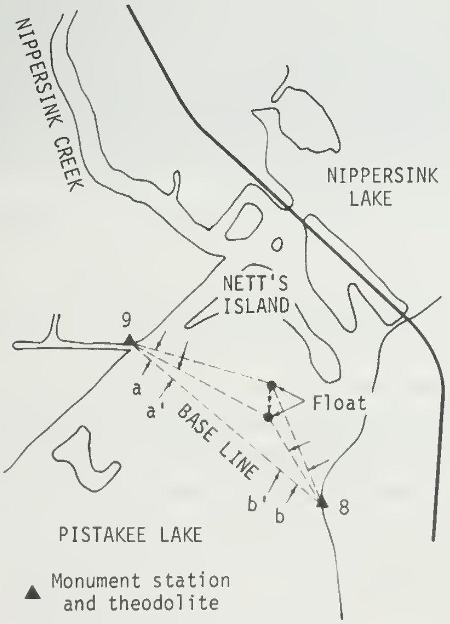


Figure 23. Schematic of circulation data collection

(a)

(b)

Figure 24. Float with suspended vanes in water (a) and tracking of the floats with theodolite at station 32 on the west shore of Lake Marie (b)

Sustained wind blowing from any direction on a lake or reservoir will generate some movement of water in the lake. This is termed wind current or wind-generated circulation. It was suspected that wind-generated currents in the Chain of Lakes would be significant and should be investigated for the present study. A recording wind set was thus installed in the Chain of Lakes, whenever field data on circulation patterns were collected. Figure 25 shows the installed wind set at Korpan's Landing on the shore of Fox Lake. These wind data were analyzed and subsequently used in conjunction with the circulation data.

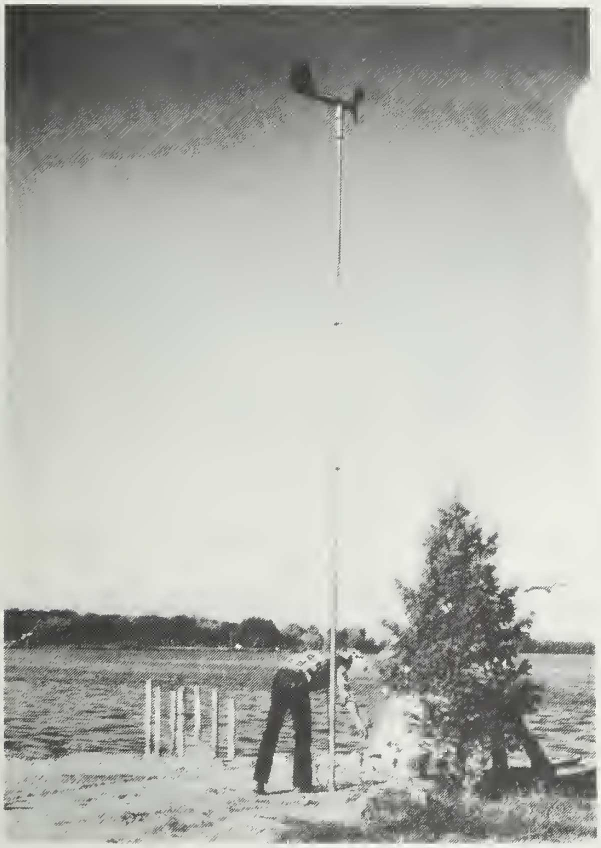


Figure 25. Wind set installed at Korpan's Landing on the shore of the Fox Lake

DATA ANALYSES

Depth-Area and Depth-Storage Relationships

To estimate the effective volume of any lake for hydraulic detention time, knowledge of the depth-area and depth-storage relationships is essential. Development of the depth-storage relationship requires up-to-date information related to bed topography of the lakes. Data on 1975 bed elevations were collected at only 26 cross sections in all of the lakes. This information was superimposed on the maps published by the Division of Water Resources to obtain an adjusted 1975 bed topography for the lakes. Because only one or two cross sections were measured in some of the lakes, the estimates required a considerable amount of judgment, though in most cases the 1975 bed topography determined in this manner should be satisfactory.

The modified maps with contour lines representing the 1975 lake bottoms were used in the development of the depth-area and depth-storage relationships. The surface areas of each lake at each selected contour interval were planimetered, the storage capacity was computed, and the individual relationships were then developed.

The depth-area and depth-storage relationships for all the lakes are shown in figures 26-30. Lake Catherine and Channel Lake are the deepest lakes in the Chain and Grass Lake is the shallowest. Pistakee Lake has the largest surface area and storage capacity among the lakes. The average depths are as follows on the next page:

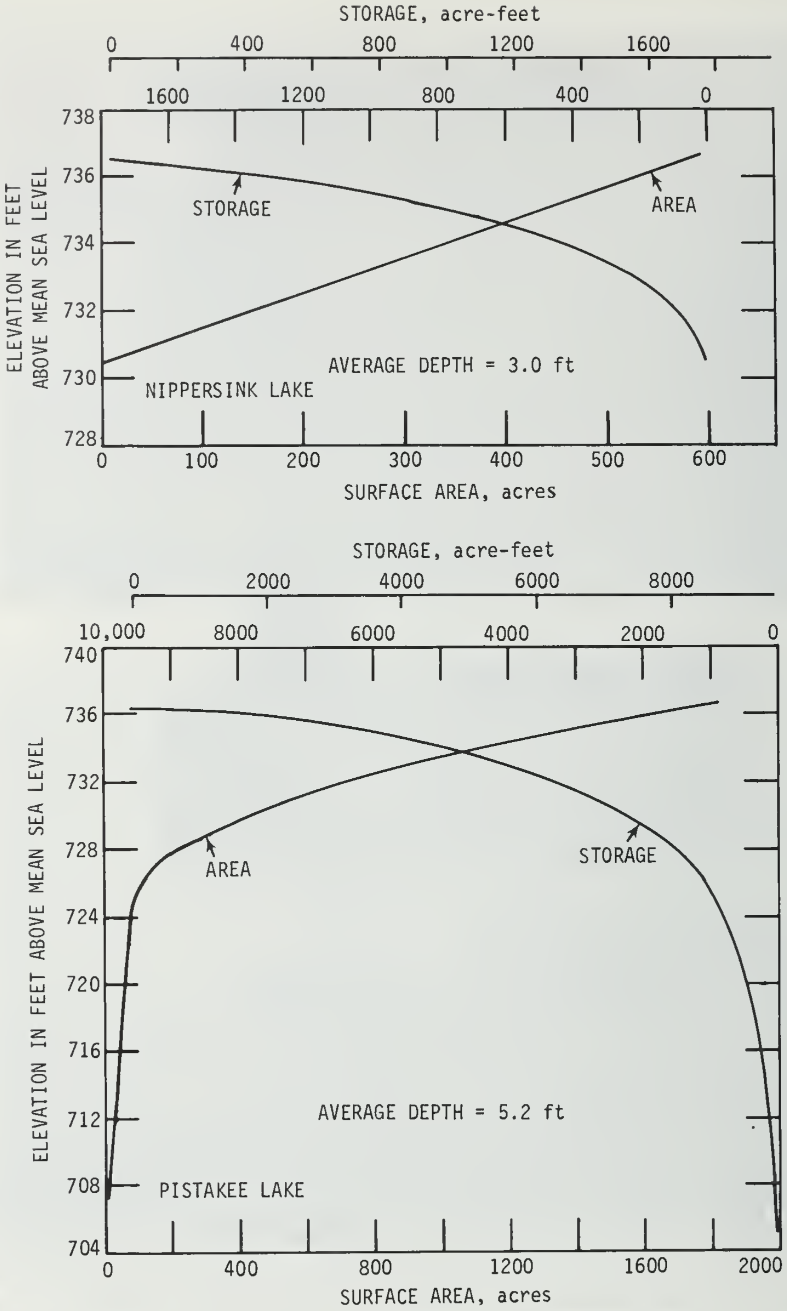


Figure 26. Depth-area and depth-storage relationships for Pistakee and Nippersink Lakes

	(feet)		*(feet)*
Pistakee Lake	5.2	Petite Lake	7.7
Nippersink Lake	3.0	Bluff Lake	10.5
Pistakee Bay	11.3	Grass Lake	2.7
Lake Catherine	16.7	Lake Marie	9.2
Fox Lake	5.6	Channel Lake	13.8

The total 1975 storage capacity of all 9 lakes below the elevation of 736.5 feet above msl is 38,718 acre-feet and the total water surface area at this elevation is 6844 acres. The total storage capacity of all the lakes below the 20-foot depth or 716.5 feet elevation

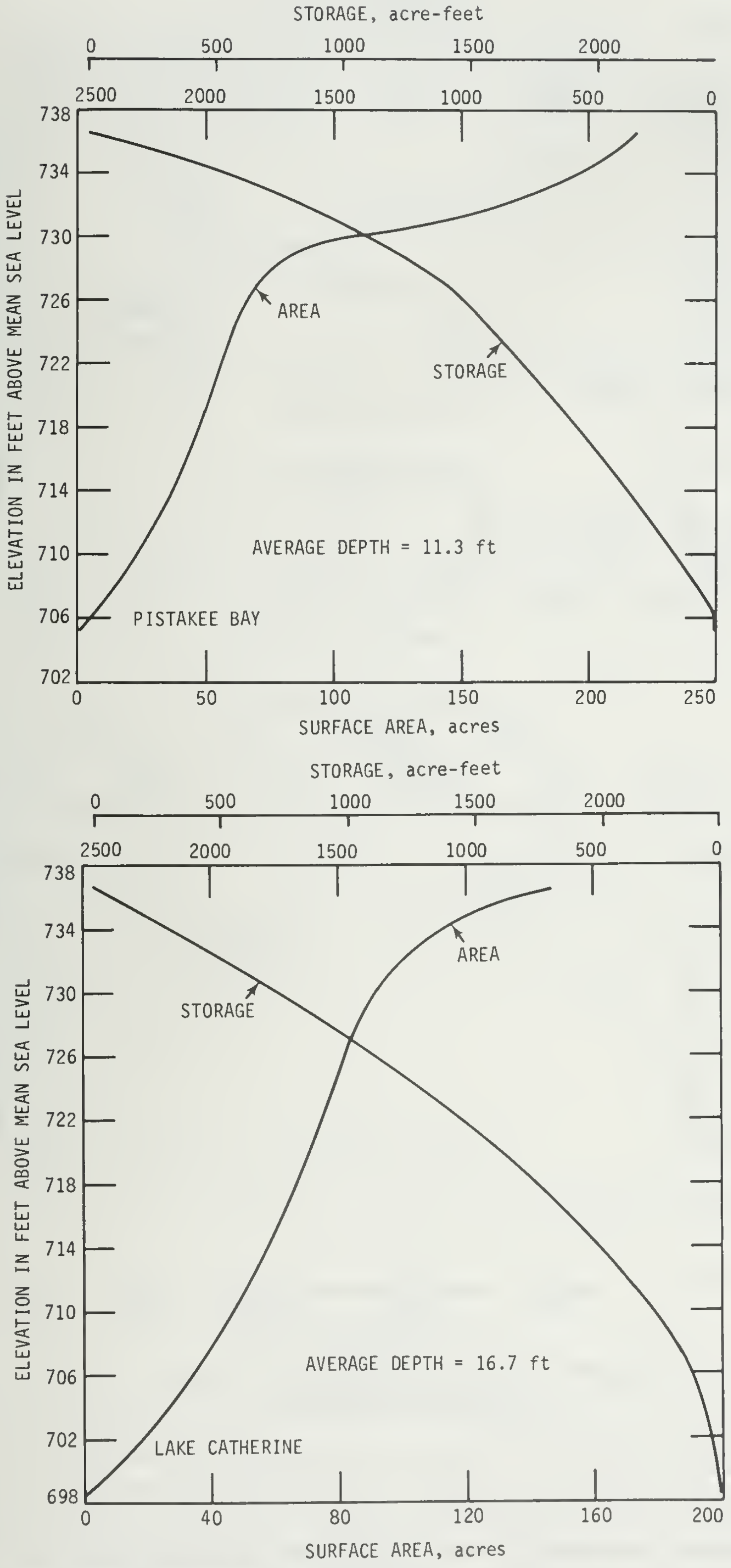


Figure 27. Depth-area and depth-storage relationships for Pistakee Bay and Lake Catherine

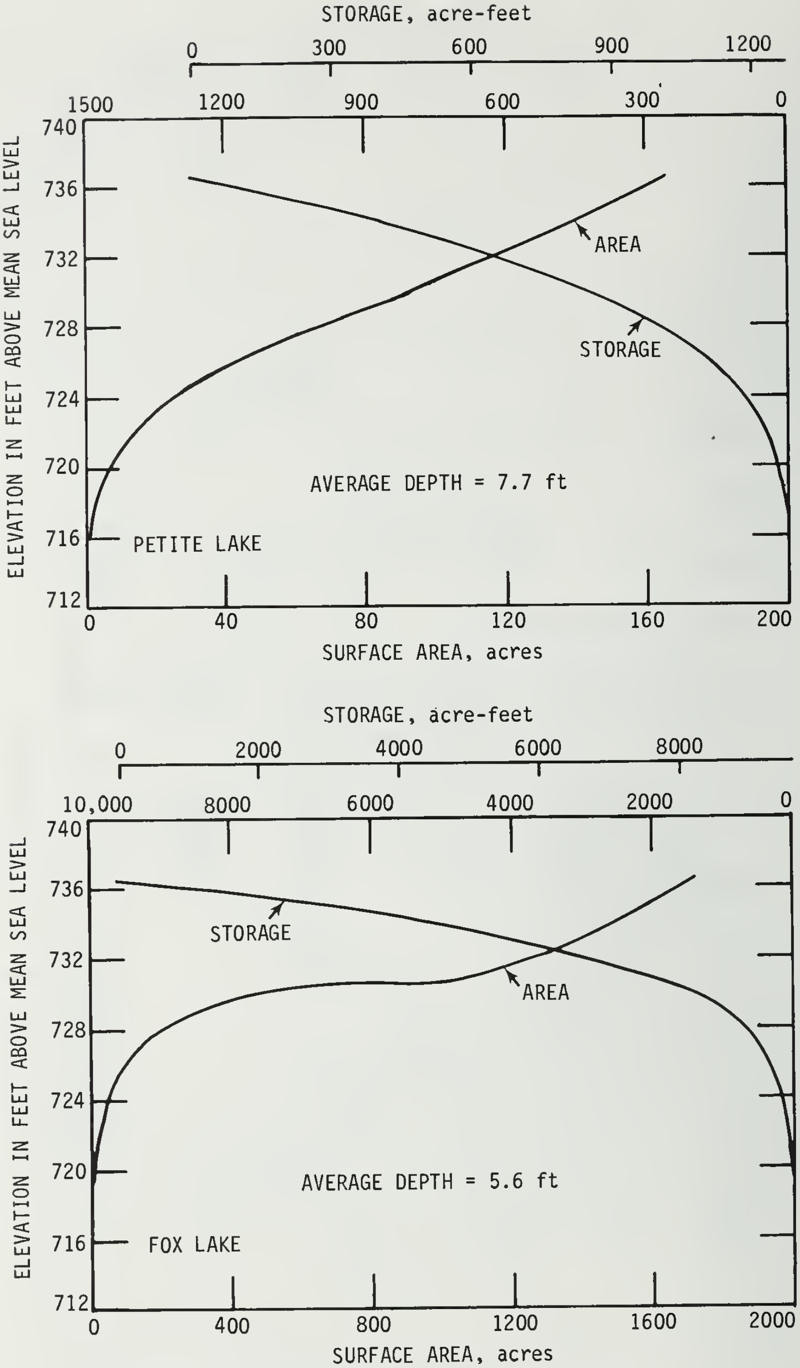


Figure 28. Depth-area and depth-storage relationships for Petite Lake and Fox Lake

is 2161 acre-feet or about 6 percent of the total storage capacity. However, most of this storage is in Channel Lake and Lake Catherine. For example, the storages below the 20-foot depth in Channel Lake and Lake Catherine are 19 and 25 percent, respectively, of the capacities of those lakes. For Pistakee Lake, Lake Marie, and Bluff Lake, the storage below that depth is 2.7, 7.4, and 10.9 percent, respectively, of their total capacities.

In general, lakes less than 20 feet deep are homogeneous in character. Stratification

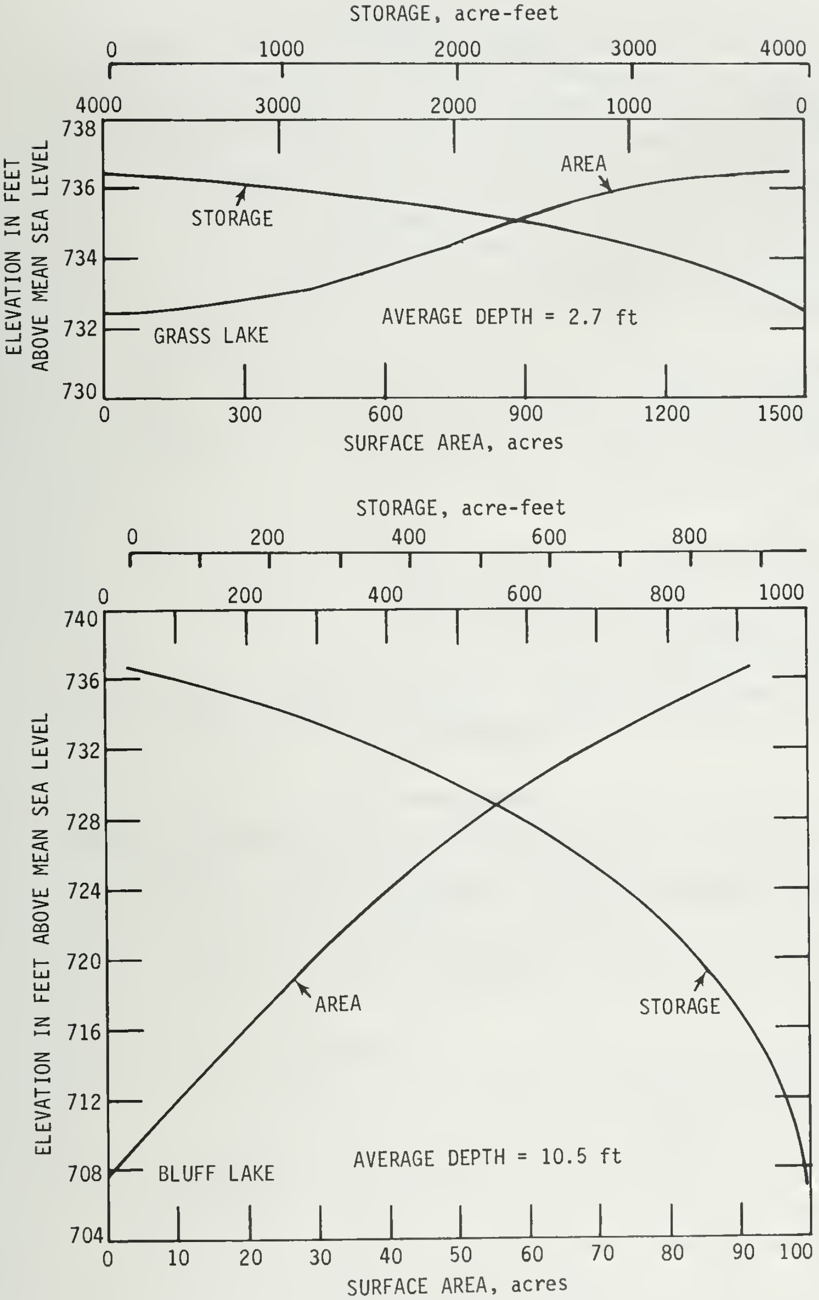


Figure 29. Depth-area and depth-storage relationships for Grass Lake and Bluff Lake

in lakes may occur when depths of the lakes exceed about 20 feet. Therefore, the depth-storage relationships are essential for the analysis of dead storage for water quality studies.

Depth Soundings

It has already been pointed out that depths were measured at 26 cross sections in the lakes. The sounding results were compared with the depths of the lakes published in a set of five maps by the Division of Water Resources (DOWR), from lake bed elevations measured in the years 1953, 1962, and 1964.

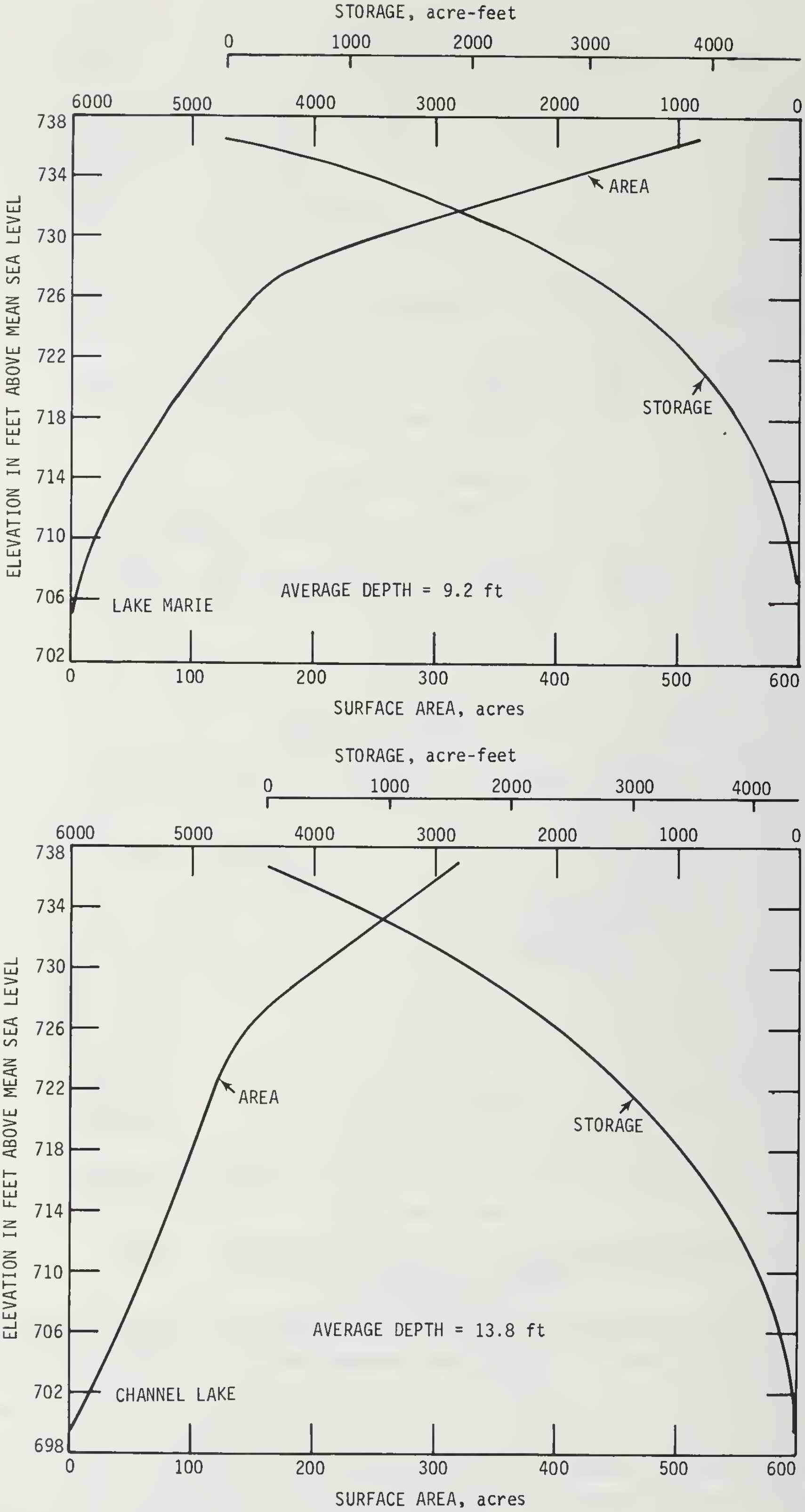


Figure 30. Depth-area and depth-storage relationships for Lake Marie and Channel Lake

The comparison of the two sets of depth measurements at the 26 cross sections indicates the variability of the lake bed and shows any sedimentation or scour pattern that might have occurred in the last 11 to 22 years. Readers must be warned that the data published by DOWR show the depth to the nearest 1 foot, and that the points where 1975 bed elevations were measured do not always coincide with those used for the DOWR maps. This necessitates some interpolation of the DOWR data to obtain an exact elevation at the points used in 1975.

The 1975 bed elevations at all the cross sections were plotted, as were the old bed profiles from the DOWR maps. Some general comments and conclusions may be drawn as to the areas and rates of sedimentation and/or erosion in the lakes. Locations of the lakes and cross sections are shown in figure 21.

Grass Lake. The 1975 bed elevations were determined only at cross section 27-28. DOWR mapped Grass Lake in 1962. A comparison of the two measurements showed that for all practical purposes bed elevations did not undergo any significant change in the last 13 years. It is probable that Grass Lake may be in a state of equilibrium for the present inflow and outflow conditions.

Lake Marie. Depths were measured at four cross sections in Lake Marie. DOWR mapped this lake in 1964. At cross section 33-35, some sedimentation did occur in the last 11 years with a maximum deposition in the order of 3 to 4 feet. Cross section 33-34 showed both deposition and some erosion. Cross section 31-33 showed some substantial amount of deposition near the middle of the lake. The maximum deposition was in the order of 5 to 6 feet. Cross section 31-32 did not show any significant variation. In general Lake Marie appeared to have lost some capacity.

Channel Lake and Lake Catherine. These are the two northernmost and deepest lakes in the Chain of Lakes system. Channel Lake is connected with Lake Marie at two locations (figure 13). Depths were measured at four cross sections. Cross section 36-37 indicated some deposition for almost the whole width of the lake except for a little erosion near the eastern shore. The maximum deposition was in the order of 2 to 3 feet. Cross section 38-39 appeared to have been eroded almost the full width of the lake. The maximum erosion was in the order of 2 to 3 feet.

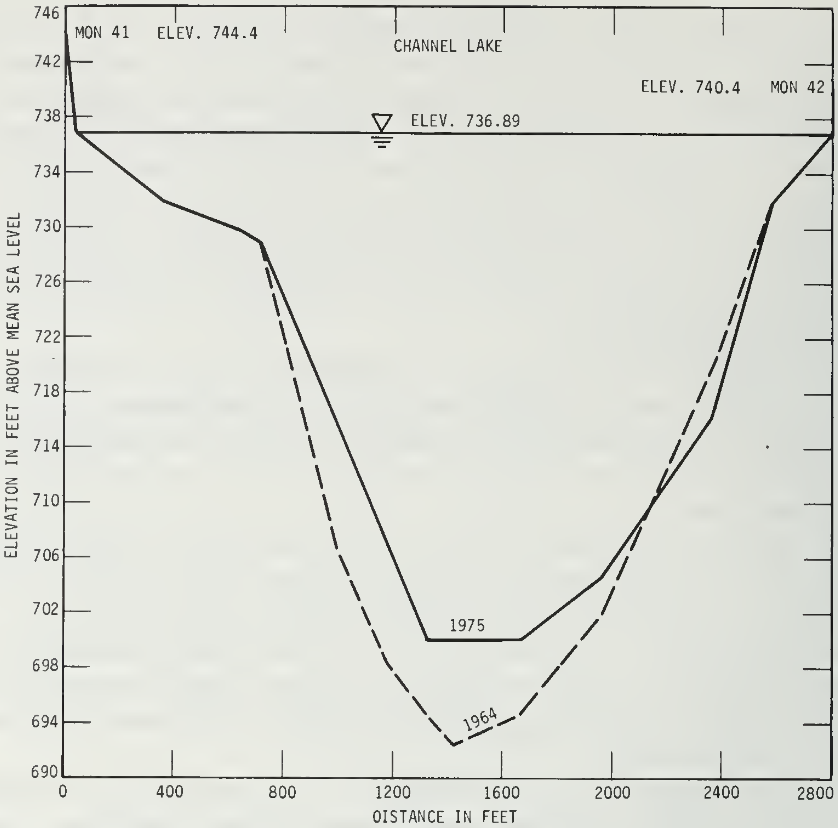
The 1975 bed elevations of the lake at cross section 41-42 were surprising, since they indicated the greatest sedimentation in any of the lakes. Figure 31 shows a comparison of the old and new cross-sectional profiles. A maximum of 7 to 8 feet of sedimentation since 1964 was evident. In contrast, cross section 40-41 in figure 31 showed some deposition near both shores and some erosion near the middle of Lake Catherine. The maximum erosion in this cross section is in the order of 3 feet.

Bluff Lake. Depths were measured at only one cross section in this lake. No measurable variations were observed. DOWR mapped this lake in 1964.

Petite Lake. For this lake also, depths were measured at only one cross section. Some sedimentation near both the east and west shores and some erosion near the middle of the lake were observed, but the net variation was negligible. DOWR mapped this lake in 1964.

Fox Lake. Depths were measured at four cross sections in this lake. DOWR mapped this lake in 1962. Cross sections 17-18 and 20-21 did not show any significant variations for this 13-year period. Figure 32 shows the old and new cross-sectional profiles between monuments 20 and 21.

The southwestern areas of Fox Lake showed some significant amount of sedimentation. Cross sections 13-16 and 15-16 showed similar variations. The maximum depth measured was in the order of 14 feet; a comparison with 1962 data indicated a maximum deposition of about 6 feet. Figure 32 shows the old and new cross-sectional profiles between monuments 15 and 16.



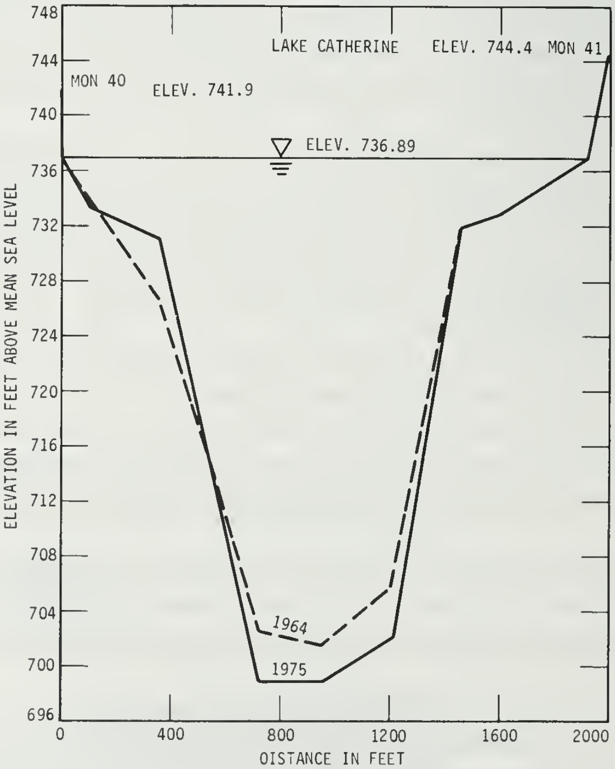


Figure 31. Typical old and new cross-sectional profiles for Channel Lake and Lake Catherine

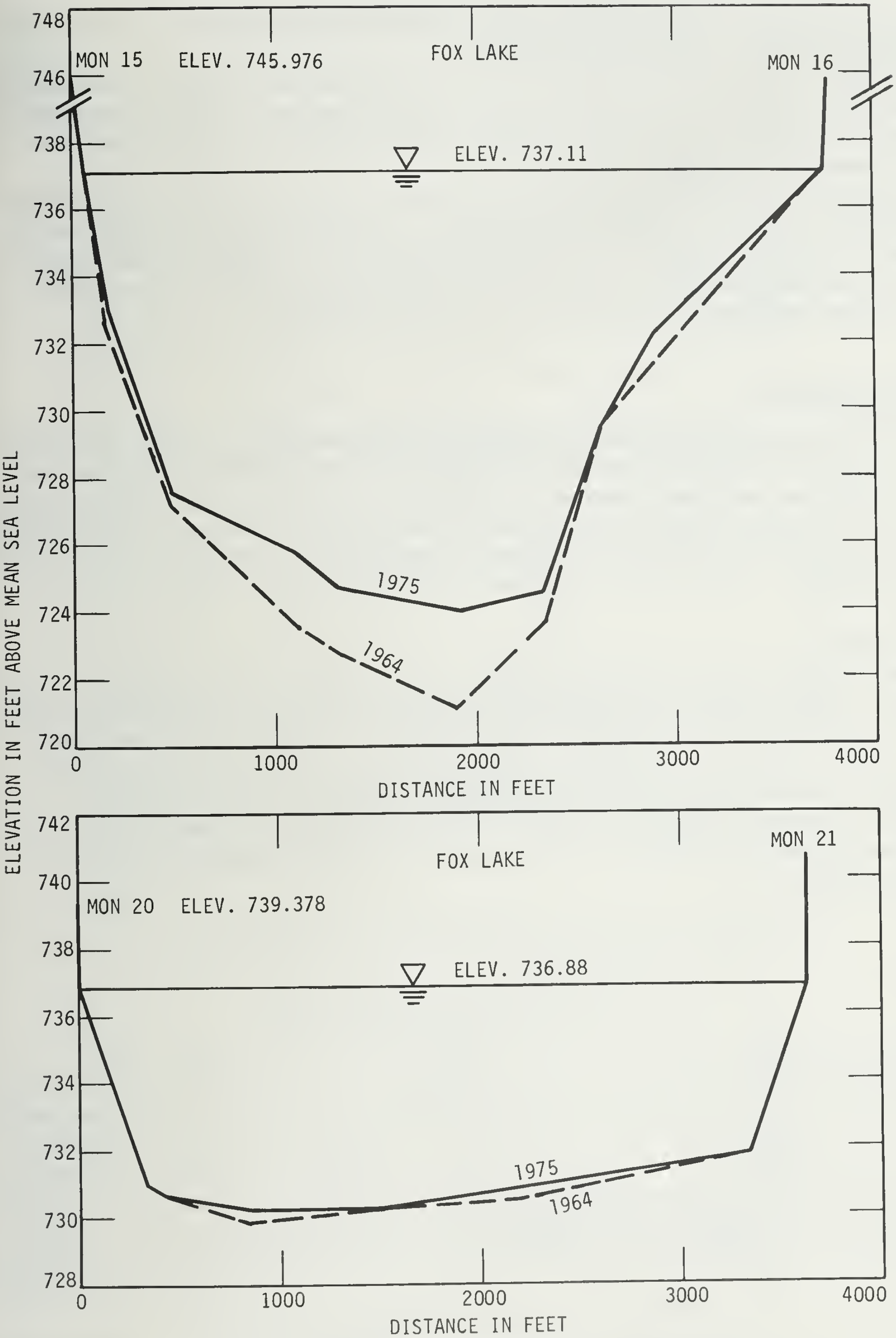


Figure 32. Old and new cross-sectional profiles for Fox Lake

Nippersink Lake. Depths were measured at three cross sections in this very shallow lake. No measurable variations in depths were observed.

Pistakee Lake. Depths were measured at seven cross sections in this lake. No significant variations were observed in most of them. However, at cross section 1-2 some sedimentation near the western half and some erosion near the eastern half were observed, though the net cross-sectional variation was negligible.

In general it can be concluded that the northernmost lakes such as Lake Marie and Channel Lake showed the maximum amount of sedimentation. The southwestern portion of Fox Lake also showed a significant amount of sedimentation. The rest of the lakes did not show much variation. Data related to depths at many more cross sections are needed to analyze precisely the extent of sedimentation and/or erosion rate in any one of the lakes.

Inflows and Outflows

One of the main objectives of this investigation was to analyze the inflows and outflows in the Fox Chain of Lakes and to quantify the water budget. As previously pointed out, data on inflows and outflows were either collected in the field or gathered from other available sources. Since in the water quality studies, the basic data for water year 1975 (September 1974 to October 1975) were utilized, it is of interest to investigate whether the 1975 water year in the Chain of Lakes region represents an average year when compared with long-term flow records.

Average Discharges

Mean monthly discharges for the Fox River gaging station at Wilmot, Wisconsin, for July 1974 through September 1975 are plotted as solid lines in figure 33. The average monthly flows for the year 1961 to 1974 are shown as dashed lines. As can be seen, the average flow of the Fox River at Wilmot for 1974-1975 was greater than the long-term average. Similar relationships for the Nippersink Creek near Spring Grove and the Fox River at McHenry Lock and Dam are shown in figures 34 and 35. These two figures also indicate that the 1974-1975 inflow and outflow at the Chain of Lakes were above average compared with long-term average flows.

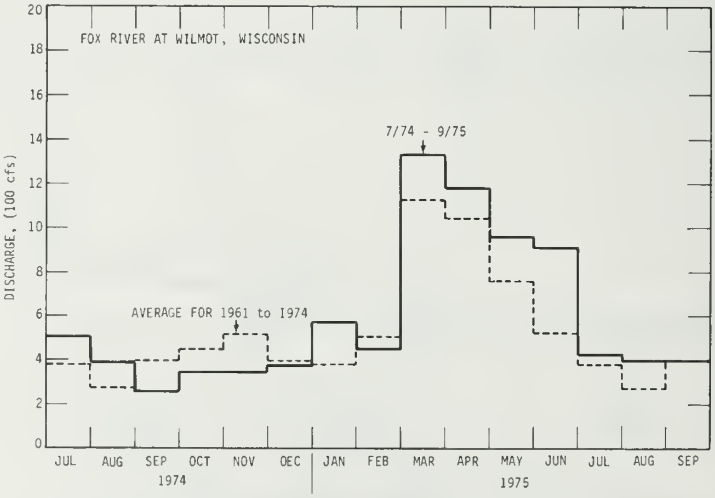


Figure 33. Monthly mean discharges for 1974-1975 and long-term mean discharges for the Fox River at Wilmot, Wisconsin

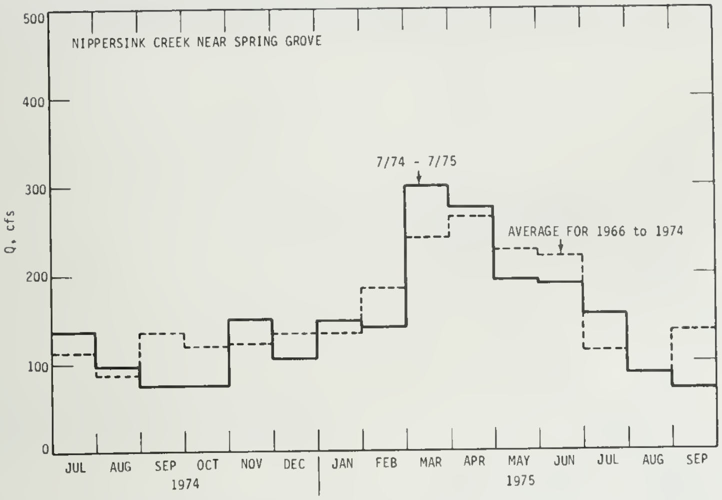


Figure 34. Monthly mean discharges for 1974-1975 and long-term mean discharges for Nippersink Creek near Spring Grove

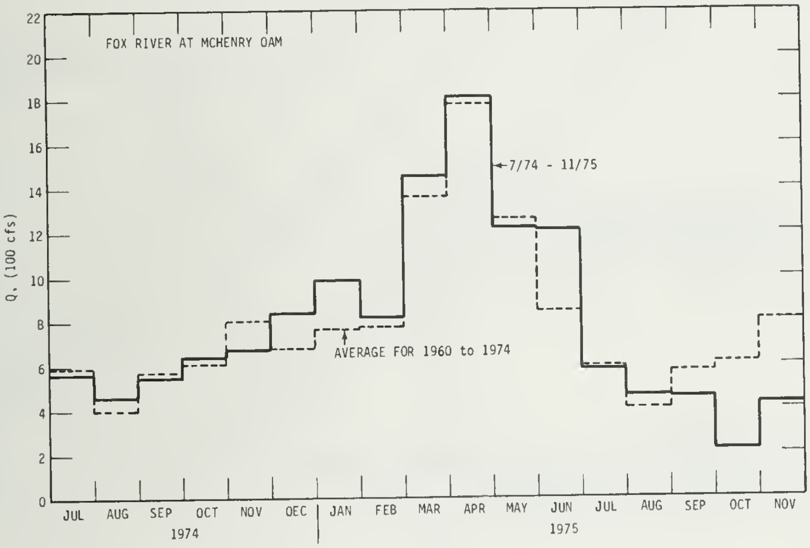


Figure 35. Monthly mean discharges for 1974-1975 and long-term discharges for Fox River at McHenry Dam

Figure 36 shows the flow duration curves for the three permanent gaging stations in the Chain of Lakes region: Fox River at Wilmot, Wisconsin; Nippersink Creek near Spring Grove; and Fox River at Algonquin. Figure 36 indicates that the frequency of occurrence of the mean flow for the 1975 water year for the Fox River at Wilmot is 22 percent; for Nippersink Creek at Spring Grove, 34 percent; and for the Fox River at Algonquin, 24 percent. The frequency of occurrence indicates the percent of time the flow either exceeded or equaled this value. The frequency of occurrence of the long-term average flows is also indicated on figure 36. For two stations, the 1975 average flow occurred less frequently than the long-term average discharges.

Water Budget

Figure 37 shows the inflows for the Fox River at Wilmot and for Nippersink Creek near Spring Grove for October 1974 through September 1975. The maximum flows occur in

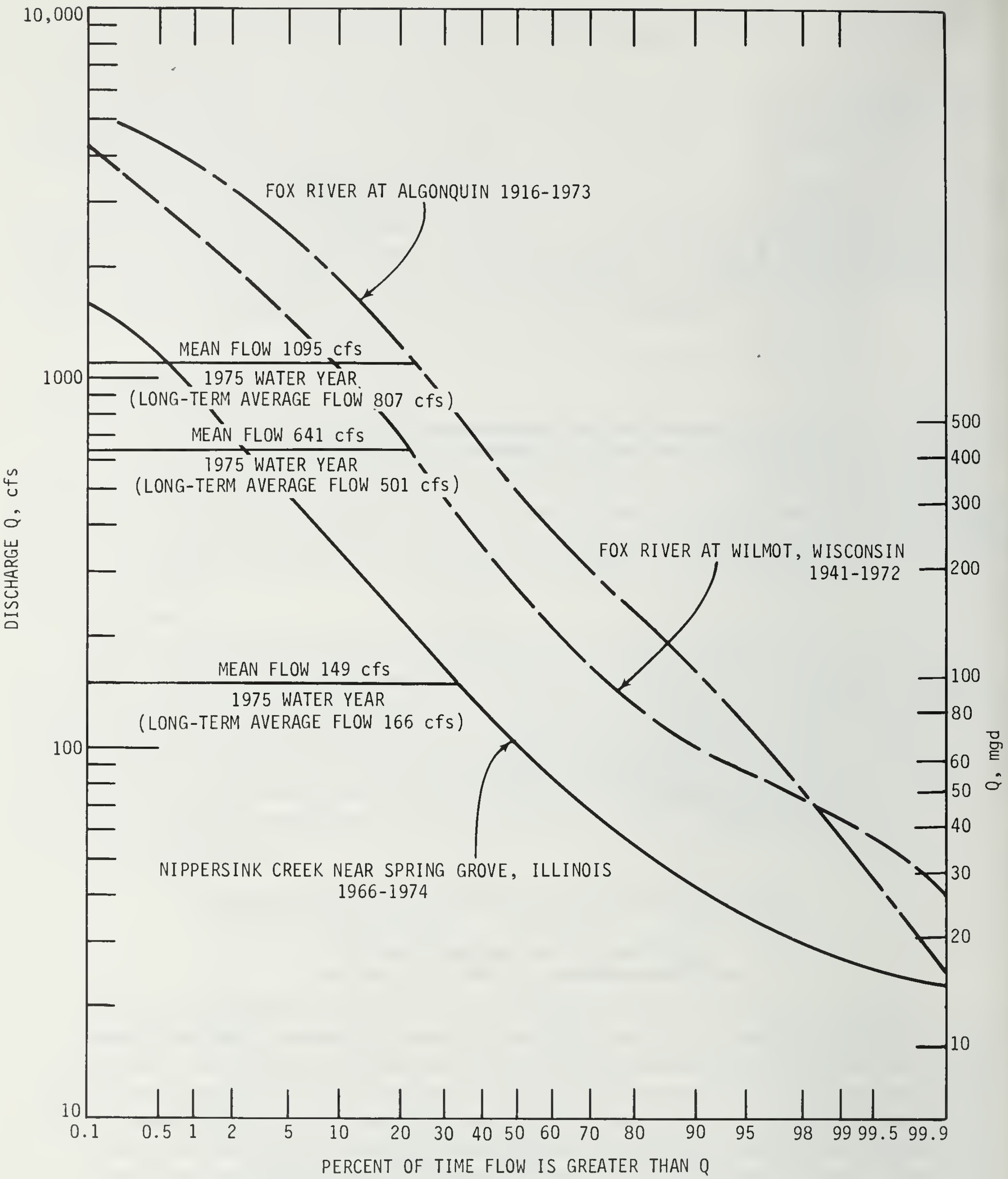


Figure 36. Flow duration curves for gaging stations in Chain of Lakes region

the months of March through June. Figure 38 shows the inflow record for Sequoit Creek near Antioch, Squaw Creek near Fox Lake, and Lily Lake Drain near Johnsburg for the months of January through November 1975, and the precipitation for July 1974 through

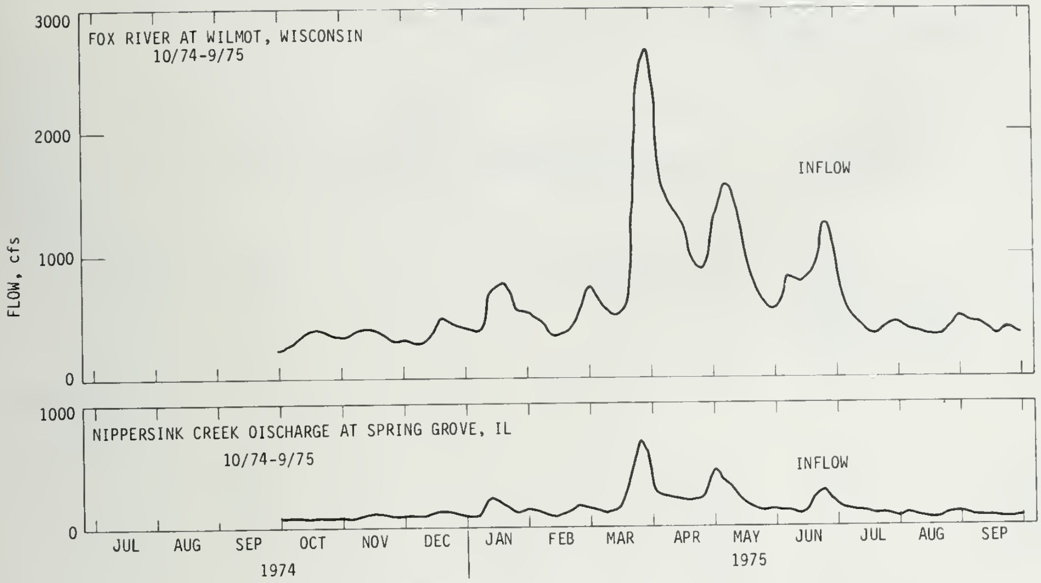


Figure 37. Major inflows to Chain of Lakes

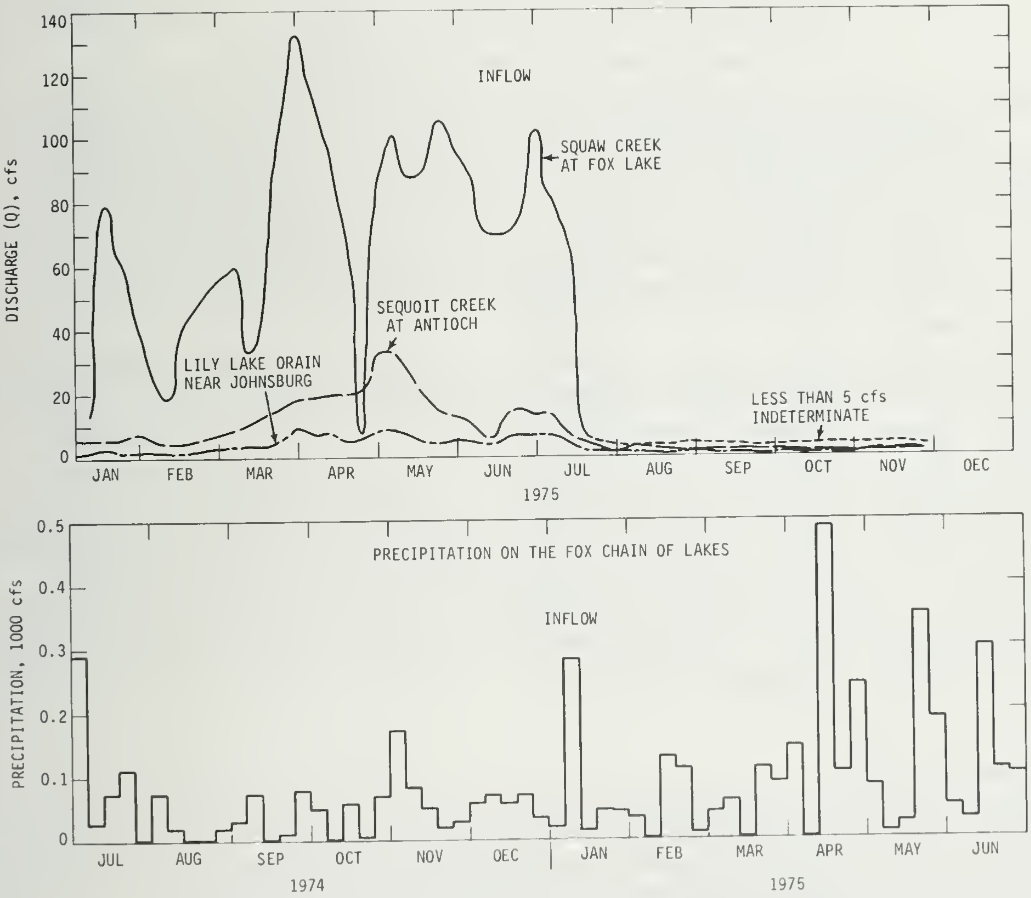


Figure 38. Minor tributary inflows and precipitation for Chain of Lakes

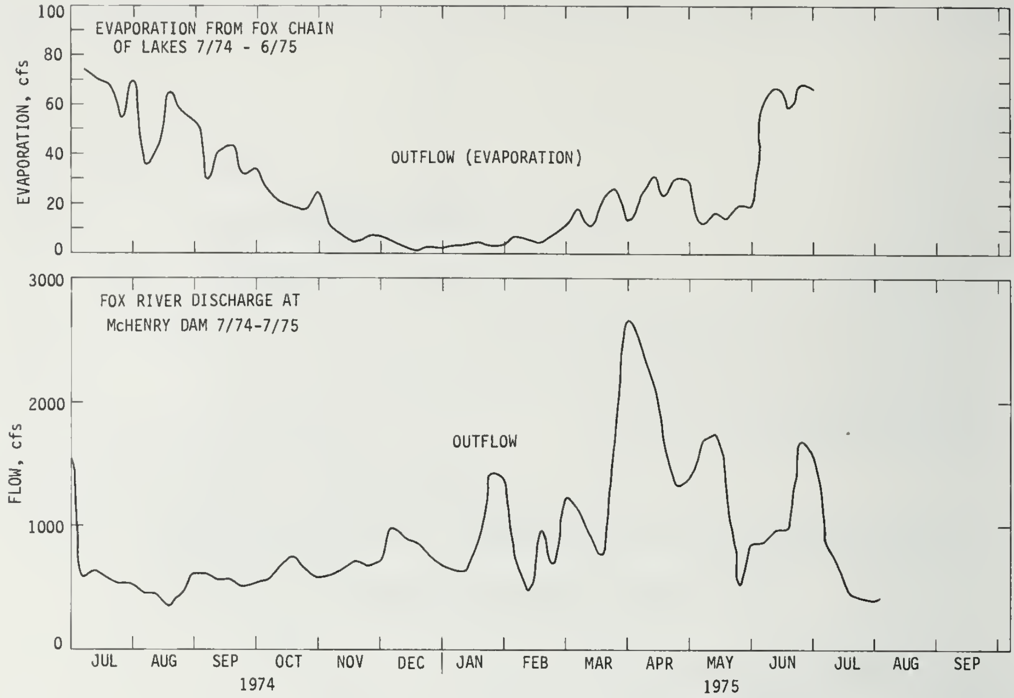


Figure 39. Evaporation losses for lakes and outflow at McHenry Dam

June 1975. The maximum inflow from Sequoit Creek occurs in April and May, and for Squaw Creek in March and April. Maximum precipitation occurs in April through June. Figure 39 shows the evaporation for the months of July 1974 through June 1975 and the outflow records at McHenry Lock and Dam from July 1974 through July 1975. The evaporation was computed following the procedure suggested by Roberts and Stall (1967). Maximum evaporation occurred in June through August and the maximum outflow occurred in April through June.

All of the inflow and outflow records shown in figures 37-39 were combined and tabulated, and a weekly water budget computation was made. Table 11 shows typical water budget computations for August 1974 and April 1975. For both of these months total outflow exceeded the inflow. However, it must be pointed out that the outflows and inflows considered here were the ones that could be measured or computed. There are some other minor inflows from the surrounding areas which could not be accounted for in this computation. This might explain the reasons for differences in inflow and outflow values in table 11. Table 12 shows the monthly values of all the inflows and outflows for July 1974 through June 1975. As can be seen, the difference between inflows and outflows fluctuates from positive to negative values.

Interflow between Lakes

Data on interflow between lakes at selected locations were collected six times from December 1974 to November 1975. On a few occasions data could not be collected from all selected locations because of ice cover or other unavoidable circumstances.

Figure 40 shows the inflow and interflow between the lakes for December 11 and 12, 1974, and May 15, 1975. On the December dates the general flow pattern was from north to

Table 11. Fox Chain of Lakes Inflow and Outflow for August 1974 and April 1975

(Flows in cfs)

	Inflow							*Outflow*			
Time period	*Wilmot*	*Nippersink Creek*	*Squaw Creek**	*Lily Lake Drain**	*Sequoit Creek**	*Precipitation*	*Total*	*McHenry Dam*	*Evaporation*	*Total*	*Inflow minus outflow*
August 1974											
1-6	380	105				75	560	455	36	491	
7-12	330	85				20	425	445	43	488	
13-18	435	97				2	534	365	65	430	
19-24	425	90				1	516	435	57	492	
25-31	370	88				18	476	618	53	671	
Monthly average	388	93				23	502	464	50	514	-12
April 1975											
1-6	1530	241	114	7	19	146	2057	2440	24	2464	-407
7-12	1345	221	100	8	19	0	1693	2160	31	2191	-498
13-18	1040	213	73	5	19	489	1839	1715	24	1739	100
19-24	863	222	7	5	20	104	1221	1330	30	1360	-139
25-30	1249	461	85	8	32	243	2078	1380	30	1410	668
Monthly average	1205	272	76	7	22	196	1778	1805	28	1833	-55

*Inflow data unavailable for Squaw Creek, Sequoit Creek, and Lily Lake Drain for August 1974

south, i.e., water was moving from Grass Lake and Lake Marie into Nippersink, Fox, and Pistakee Lakes and finally to the Fox River in the downstream direction. On May 15 the basic flow pattern was also in the downstream direction with the flow from Lake Marie moving into Grass Lake. However, on May 21 when circulation data were collected between Stations 31 and 32 (figure 21) in Lake Marie, the water was flowing from Grass Lake into Lake Marie.

Figure 41 shows the inflow and interflow between lakes for July 14 and 15, 1975. Basically, the flow was moving in the downstream direction except on July 15, 1975, when water was moving from Grass Lake to Lake Marie. On July 18 the water was also moving from Grass Lake to Lake Marie.

Table 12. Water Budget for Fox Chain of Lakes, July 1974 through June 1975

(Flows in cfs)

Date	*Total inflows*	*Total outflows*	*Inflow minus outflow*
July 1974	772	660	112
August	502	514	-12
September	367	590	-223
October	461	661	-199
November	518	674	-156
December	540	839	-298
January 1975	849	988	-139
February	710	822	-112
March	1786	1468	318
April	1778	1833	-55
May	1431	1236	195
June	1316	1274	42
Average total for 1-year period	919	963	-44
	665,000 acre-feet	697,000 acre-feet	-32,000 acre-feet

Figure 42 shows the inflow and interflow between lakes for October 7 and 10, 1975. On both of these occasions, the flows under the Highway 173 bridges between Channel Lake and Lake Marie were measured with floats and vanes. Surprisingly, water was moving into Channel Lake under the east bridge on both of these days. However, on October 7 water was moving into Lake Marie under the west bridge. On October 10 water was moving into Channel Lake, and the wind was blowing

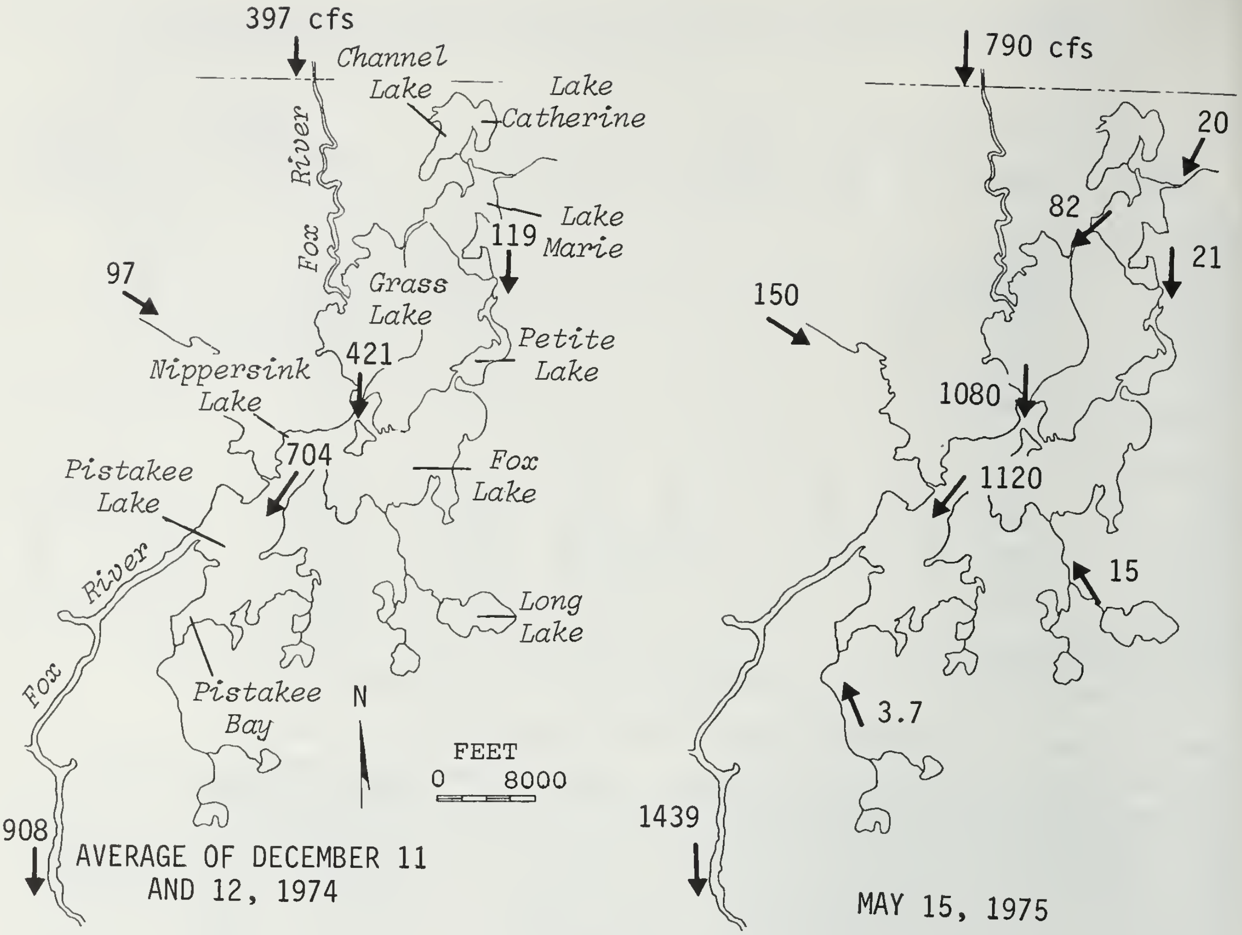


Figure 40. Inflow and interflow between lakes for December and May dates

moderately from the south or southeast at 7.5 mph. Discharge was measured between Grass Lake and Lake Marie on October 8. On this date part of the water in the cross section was flowing in one direction and part in the opposite direction, with a net flow of 1.9 cfs into Lake Marie.

The other surprising interflow data on October 7 was the 34 cfs flow into Nippersink Lake from Pistakee Lake. However, on October 9 the net outflow from Nippersink Lake was into Pistakee Lake. It appears that when the inflows are low (e.g., the 159 cfs flow at Wilmot on October 7 has a frequency of occurrence of 72 percent, figure 36) the water within the lakes wanders around and its movement may to some extent depend on wind velocity and direction. Circulation data indicated that on October 7 and 10 water was basically moving into Lake Marie from Grass Lake.

Figure 43 shows the inflow and interflow between lakes on October 23 and November 18, 1975. On both of these days, there was a net outflow from Lake Marie into Channel Lake. The data from the four fall days (October 7, 10, 23, and November 18) showing a net outflow from Lake Marie into Channel Lake came as a surprise. It appears that strong winds move water from Lake Marie toward the northeast, piling it up in Channel Lake and Lake Catherine. This excess water will of course return to Lake Marie and down to the Fox River when the wind subsides.

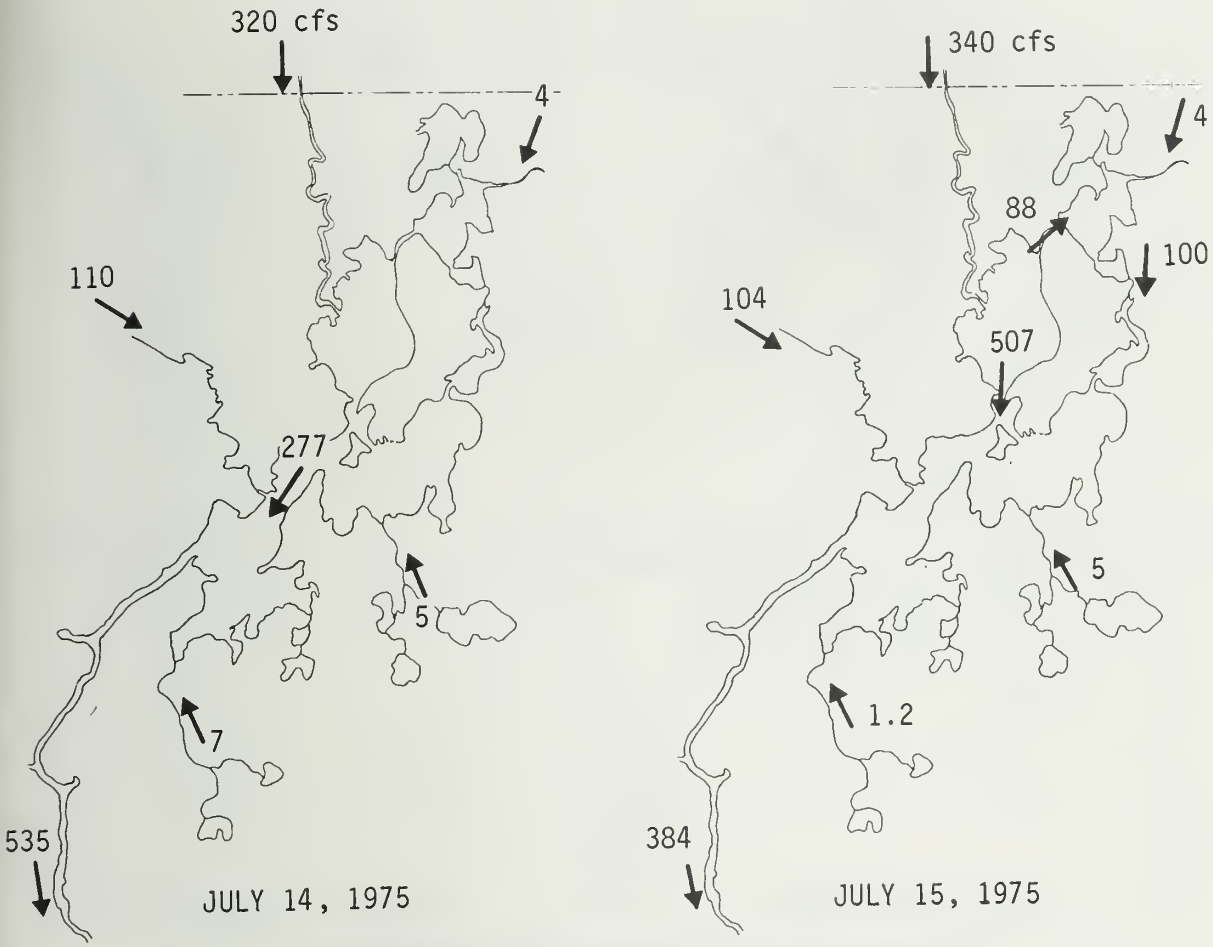


Figure 41. Inflow and interflow between lakes for July dates

Table 13. Flow Velocity under Highway 173 Bridges

	East bridge			*West bridge*		
Date	*Flow (cfs)*	*Average velocity (fps)*	*Direction*	*Flow (cfs)*	*Average velocity (fps)*	*Direction*
October 7, 1975	77	0.127	Into Channel Lake	9.2	0.111	Into Lake Marie
October 10, 1975	108	0.178	Into Channel Lake	2.0	0.033	Into Channel Lake
October 23, 1975	33	0.052	Into Channel Lake	7.0	0.117	Into Lake Marie
November 18, 1975	113	0.182	Into Channel Lake	8.0	0.125	Into Channel Lake

Some computations were made to estimate the flow velocity under the Highway 173 bridges at the time the discharge was estimated with floats and vanes, as shown in table 13. The maximum average velocity measured is on the order of 0.182 fps. Although this average velocity is low, it is capable of transporting fine materials in suspension. Moreover, these velocities were measured on only four days in a year. Flow may increase under these bridges at other times of the year with higher velocities.

Circulation data (to be presented in a later section) and the interflow data presented in figures 40–43 show that in general water moves from Grass Lake into Lake Marie, but that water also moves into Channel Lake from Lake Marie at least when the data were collected. The observed peculiar flow patterns may be a clue to the heavy sedimentation rate observed in

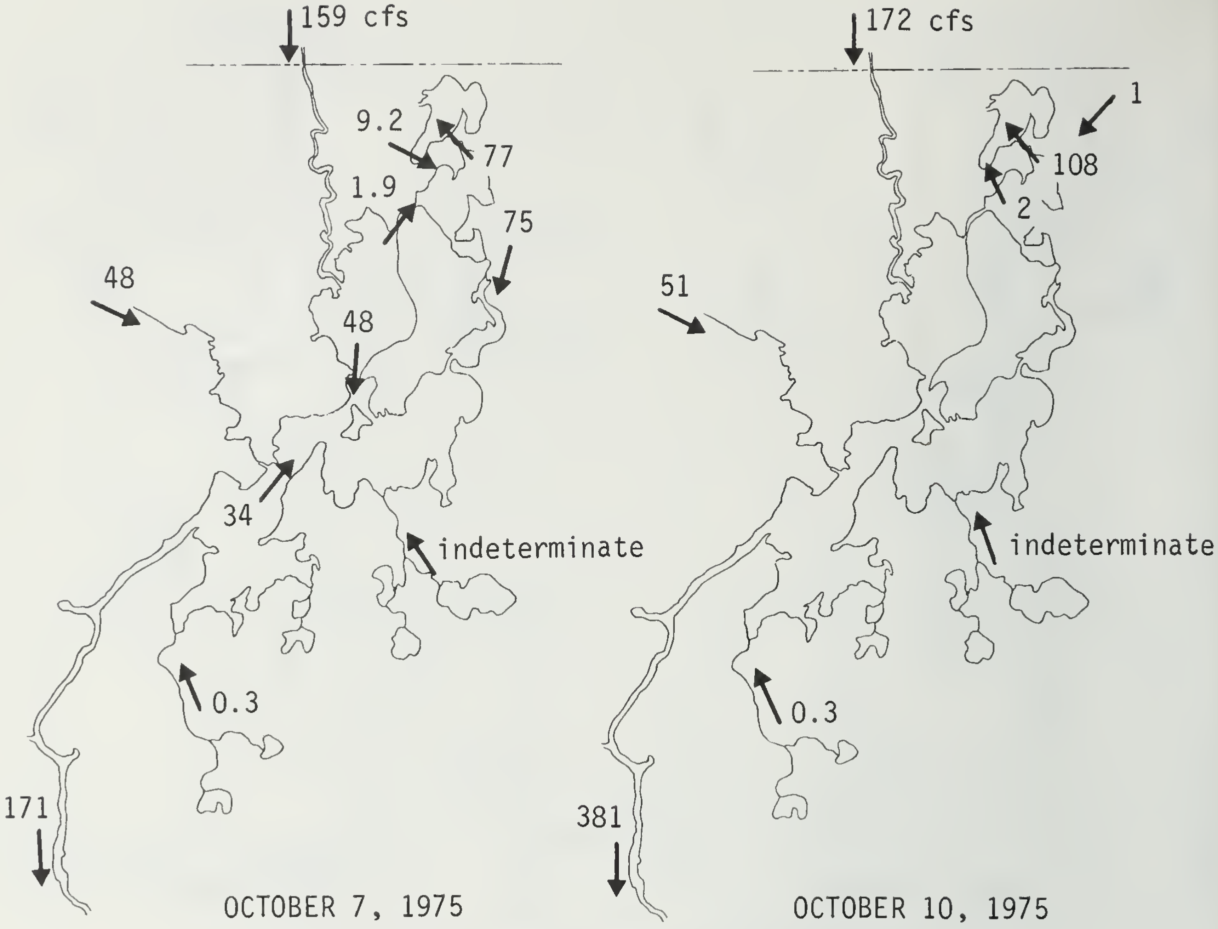


Figure 42. Inflow and interflow between lakes for early October dates

Channel Lake, as was shown in figure 31. It appears that the water moving into Channel Lake carries some fine materials. These may have originated from Fox River water moving through Grass Lake to Lake Marie and ultimately to Channel Lake. Or, part of the load may come from bed erosion at the southern part of Channel Lake in the vicinity of cross section 38-39, the materials being finally deposited in the deeper part of Channel Lake near cross section 41-42 (figures 21 and 31).

In general, it appears that when inflow rates are high, water generally moves in a southwesterly direction and eventually flows down the Fox River. However, during low inflow rates, the general movement of water within the lakes is erratic, and the water wanders to and fro depending on wind velocity and direction until it finally flows downstream through the Fox River. This complex nature of the flow makes it difficult to establish a reliable hydraulic detention time in the Chain of Lakes.

Theoretical Hydraulic Detection Times

The theoretical detention times in the lakes were computed for various inflow and outflow characteristics. For this computation, lake levels were assumed to be at 736.5 feet above msl. Initially, it was assumed that the lakes were homogenous, that total storage capacities of the lakes were effective in retaining the inflows, and that a somewhat uniform

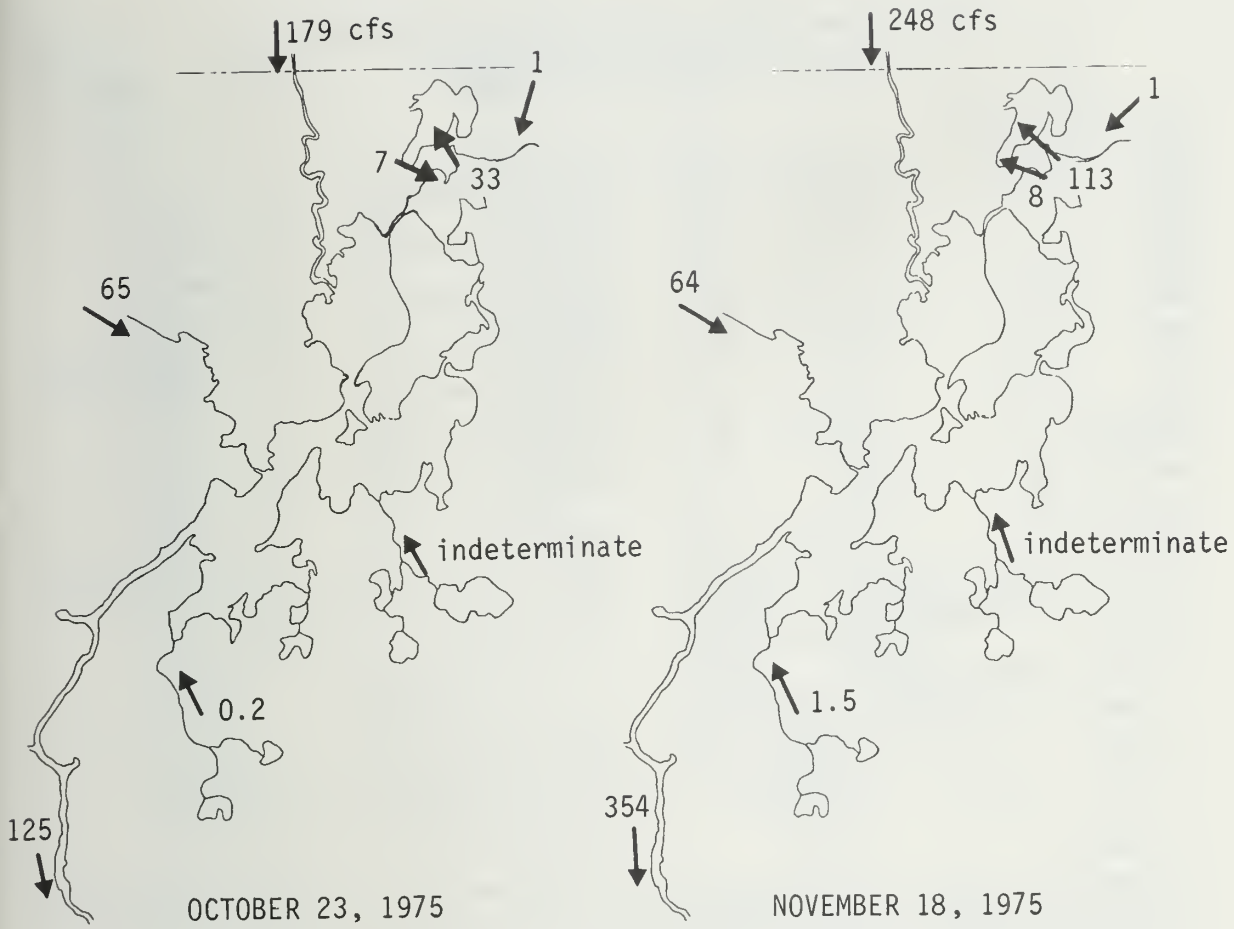


Figure 43. Inflow and interflow between lakes for October 23 and November 18

type of flow existed throughout the time it took the inflow to pass through the lakes. With these gross assumptions, computations were made to estimate the detention times in all the lakes.

Detention times for flows of July 14 and 15, 1975 (figure 41), and the associated assumptions that were used in the computations are given in table 14.

Inflow data into Channel Lake and Lake Catherine were collected on a few occasions (figures 42 and 43), and the detention times for these two lakes on October 7, 1975 (figure 42), also are given in table 14.

Average Detention Time in Chain of Lakes. The following computation was made to get some idea about an average detention time in all of the Chain of Lakes. This average discharge is obtained by multiplying with the proportional factor of the drainage areas at McHenry Lock and Dam (1253 square miles) and the Fox River near the outlet of Pistakee Lake (1207 square miles). The average outflow at McHenry Lock and Dam for the years 1960 to 1974 is 869 cfs. Therefore, the average outflow at the mouth of the Fox River near the outlet of Pistakee Lake is estimated to be (869 x 1207)/(1253) = 837 cfs. It is assumed that the end product of all the inflows, precipitation, evaporation, effluents, and influents is an average outflow of 837 cfs at Johnsburg. The total storage capacity of all the lakes below a water surface elevation of 736.5 feet above msl is 38,718 acre-feet. Therefore, the average detention time is 23.32 days. If we assume that neither all the lakes nor their full capacities are effective in retaining this flow, then the detention time becomes 10.79 days (table 14).

Table 14. Detention Times in the Chain of Lakes for Given Flow Periods

Lake	*Storage (ac-ft)*	*Q (cfs)*	*Special provision*	*Detention time (days)*	*Remarks*
July 14 and 15, 1975					
Grass	3,983	468.4	Full capacity	4.3	
Grass	2,390	468.4	60 percent capacity	2.6	
Marie	4.742	92	Full capacity	26	
Marie	3,685	88	Western part of lake only	21.1	
Bluff	965	100	Full capacity	4.9	
Bluff		100	Upper 20 ft of lake	4.3	
Petite	1,272	100	Full capacity	6.4	
Fox	9,622	105	Full capacity	48.5	Not reasonable
Fox			50 percent capacity	97	Not reasonable
Nippersink	1,772	607	Full capacity	1.5	
Pistakee	3,016	455	Northwest part of lake	3.7	
Pistakee			Full capacity	10.6	
October 7, 1975					
Channel	4,368	77	Full capacity	28.6	
Catherine	3,540	77	Upper 20 ft only	44.7	Not reasonable
Average flow of 1960–1974					
All lakes	38,718	837	Full capacity	23.3	
Assumed effective storage					
Grass	2,390		60 percent capacity		
Marie	3,685		Western part		
Bluff	965		Full capacity		
Petite	1,272		Full capacity		
Fox	4,811		50 percent capacity		
Nippersink	1,772		Full capacity		
Pistakee	3,016		Northwest part only		
Total effective storage	17,911	837		10.8	
July 14 and 15, 1975					
Effective storage	17,911	459	Same special provisions as used above	20.4	
October 23, 1975					
Effective storage	17,911	125		75	Not reasonable
7 day 10 year low flow					
Effective storage	17,911	39.4		229	Not reasonable

Detention Time for Low Streamflow Regimen. In order to estimate a detention time in all of the lakes, the low flow value of 39.4 cfs at the outlet of Pistakee Lake was taken as representative of 7-day 10-year low flows (Singh and Stall, 1973). With this flow, detention time was 229.19 days.

It appears that during low flows, a considerable amount of time is needed to pass the flow through all of the lakes. One must understand that the flow will not, of course, stay constant for 229 days, so this estimate of detention time is not reasonable (nor are other high numbers for the specific lakes as noted in table 14). However, an estimate of 229 days points out the fact that during low flows, the water is going to wander around in the lakes for a long time.

The computed detention times are summarized in table 14. Before utilizing any value from the table, the reader must understand the limitations and assumptions that were used in the computations.

Seasonal Variation of Detention Time. Seasonal variations of the detention times were computed using the average outflow at Johnsburg for the water year 1975 (October 1974

Table 15. Theoretical Detention Time in the Chain of Lakes with Four Capacity Assumptions

(Detention times in days)

Date	*Assumption 1*	*Assumption 2*	*Assumption 3*	*Assumption 4*	*Flow at Johnsburg (cfs)*
October 1974	31.8	30.0	14.7	14.4	613
November	30.4	28.7	14.1	13.7	642
December	24.4	23.0	11.3	11.0	800
January 1975	20.6	19.4	9.5	9.3	949
February	24.9	23.5	11.5	11.2	784
March	14.0	13.2	6.5	6.3	1397
April	11.2	10.6	5.2	5.1	1739
May	16.6	15.7	7.7	7.5	1175
June	16.7	15.8	7.7	7.5	1166
July	34.9	32.9	16.1	15.7	560
August	44.2	41.6	20.4	19.9	442
September	45.4	42.8	21.0	20.5	430

1 Full capacity for all lakes

2 All lakes (only upper 20 ft of water is effective)
Storage capacity = 36,512 ac-ft

3

Grass Lake	60 percent capacity
Lake Marie	Western part
Bluff Lake	Full capacity
Petite Lake	Full capacity
Fox Lake	50 percent capacity
Nippersink Lake	Full capacity
Pistakee Lake	Northwestern part

Storage capacity = 17,911 ac-ft

4

Grass Lake	60 percent capacity
Lake Marie	Western part, upper 20 ft
Bluff Lake	Upper 20 ft
Petite Lake	Upper 20 ft
Fox Lake	50 percent capacity
Nippersink Lake	Full capacity
Pistakee Lake	Northwestern part

Storage capacity = 17,456 ac-ft

Note: Water surface at 736.5 above msl for all assumptions

through September 1975). The computed detention times, in days, with different assumptions are listed in table 15 and shown in figure 44. As can be seen, detention time can vary from 11 days in April to 45 days in September for full capacity of all the lakes. With assumption number 4 (table 15), the detention time varies from 5 days in April to about 21 days in September.

Circulation Patterns

Movement of water in any closed or open-ended body of water is induced by a number of natural or man-made factors. Inflow or outflow characteristics, temporary detention and release of water, winds blowing over the water surface, density differential due to temperature variation, and a host of other factors can start and sustain a pattern of water movement inside any lake or reservoir. When the quantity of inflow into a lake is very small compared with the total effective storage of the reservoir, the measurable pattern of water movement inside the lake will in all probability be affected by external forces such as wind blowing over the water surface.

Basic inflow to the Chain is from the Fox River and Nippersink Creek, and water in the lakes moves in a south, southwesterly direction. However, in some of the connecting areas water moves in the northeast or northerly direction (figures 40 to 43). The localized flow in any one of the lakes is sometimes variable and the water may move in a completely opposite direction from the normal flow. Moreover, except for the two northernmost lakes, all of the lakes in the Chain are basically shallow. Wind blowing over the water surface will

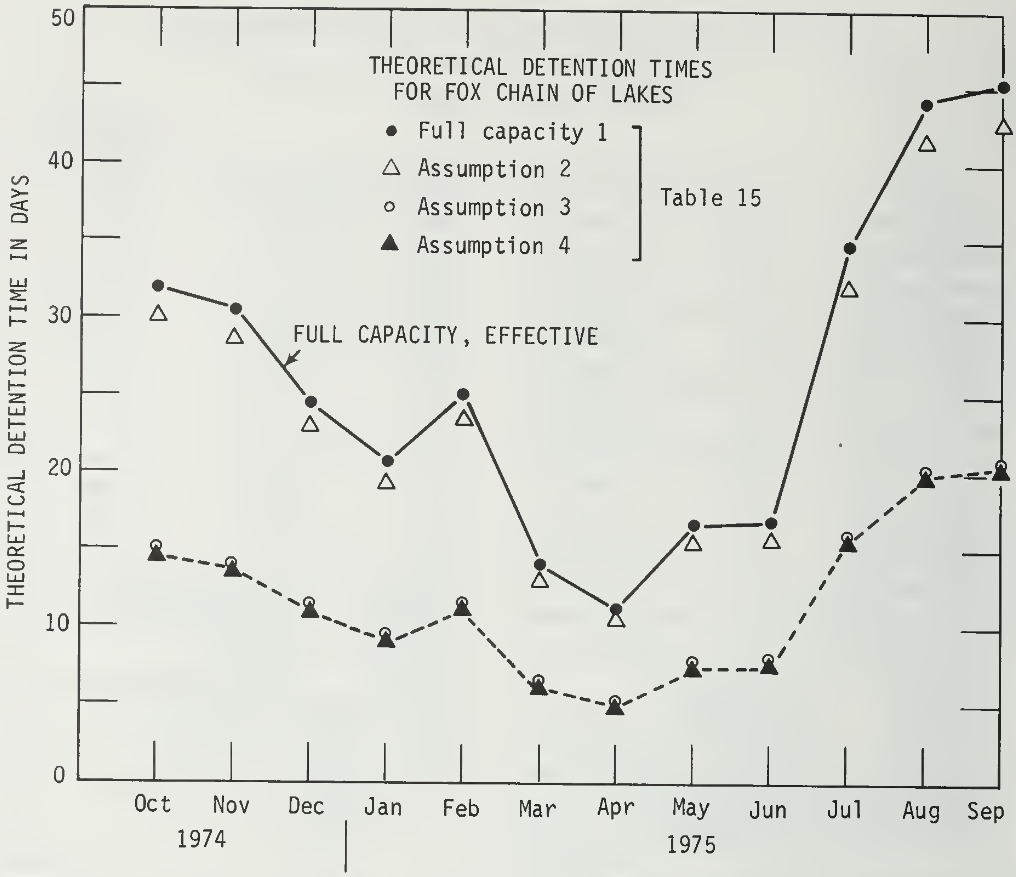


Figure 44. Theoretical detention times for Fox Chain of Lakes

transmit momentum to the water and the water will start to move with the wind. If the direction of the wind remains constant, this movement of water will attain a specific pattern and may continue for some time. Movement of water generated by the wind blowing over the water surface is called the *wind-generated circulation pattern.* The Chain of Lakes is affected by the wind, and wind-generated circulation patterns sometimes govern the interflow between some of the lakes at some time of the year.

Theory. Various investigators have studied the wind-generated circulation patterns in lakes. Most of these studies were confined to the theoretical or analytical analysis with some computer simulation to depict the water movement in the lakes. Ligget and Hadijtheodorou (1969) presented a mathematical simulation to study the wind-generated circulation patterns in shallow homogeneous lakes. They developed Calcomp plots of circulation patterns in an idealized rectangular lake. The effects of bottom topography and lake configuration were incorporated into their analysis. Ligget (1970) presented a cell method to compute three-dimensional wind-driven circulation in a homogeneous lake. This method allowed an arbitrary variation of surface wind stress and the eddy viscosities could be varied from cell to cell. A mathematical model to compute the circulation pattern in stratified lakes was also presented by Liggett and Lee (1971). Mathematical formulations of wind-generated circulation patterns were also studied by Murty and Rao (1970), Cheng and Tung (1970), Bonham-Carter and Thomas (1973), and a number of other investigators.

Laboratory investigations of circulation patterns in lakes were performed by Li et al. (1975) and Hoopes et al. (1973). These laboratory experiments shed some light on the basic mechanism of circulation patterns and enabled the researcher to study the effects of various input parameters on the development of the pattern of water movement.

Gedney and Lick (1971) computed the steady-state wind-generated circulation patterns in Lake Erie and compared their results with current meter velocities. Some current data were collected from Lake Michigan by the Federal Water Pollution Control Administration (1967). Plots of circulation patterns for varying wind conditions were shown. Drogues and current meters were used to collect the circulation data.

Wind-Velocity Distribution. The wind-velocity distribution above the ground or water surface was found to be logarithmic by some investigators. The general equation is a form of the logarithmic distribution given below:

$$V_z = (V_*/\kappa) \ln (z/z_o)$$

where V_* is the shear velocity, κ is the Von Karman's constant generally taken to be 0.4, z_o is the air roughness height. Various researchers have postulated different values of roughness height. Shemdin (1973) found the value of z_o to be 0.1 mm. Both Ruggles (1969) and Lai and Shemdin (1971) indicated that a wind-velocity profile follows a logarithmic distribution, but De Leonibus (1971) indicated that in all his field measurements, he rarely came across a logarithmic wind-velocity profile.

Surface Drift. Surface drift can be defined as the movement of the uppermost layer of water as a result of wind shear or blowing wind. However, the surface layer of water can also move because of a seiche, boat-generated disturbances, gradient currents, and differential in temperature between air and water. Many investigators have studied the surface drift phenomena and have indicated the relative magnitude of the surface current compared with wind velocity.

The ratio between surface current and wind velocity is termed the *wind factor.* Haines and Bryson (1961) have described most of the important contributions on this aspect of wind-generated current.

Ekman (*in* Haines and Bryson, 1961) has shown that

$$\text{wind factor} = V_s/V_w = (0.0127)/(\sin \Phi)^{1/2}$$

where V_s is the surface drift, V_w is the wind velocity, and Φ is the latitude. According to this relation, the surface drift is constant for any fixed latitude. For the Fox Chain of Lakes the surface drift is 0.0155 for a latitude of 42° 25′N. Rossby and Montgomery (*in* Haines and Bryson, 1961) have indicated that wind factor decreases with high latitudes and wind velocity and ranged from 2.3 to 3.2 percent. A mean wind factor of 2 percent was found to be valid in Lake Erie by Olson (*in* Haines and Bryson, 1961).

Keulegan (1951) from experiments in a laboratory tank has proposed that

$$V_s/V_w = 0.033$$

for Reynolds number greater than about 1000. Van Doren (1953), using data from a pond, obtained similar results between surface drift and wind velocity. Both of these investigators also have shown that surface drift is independent of waves. Haines and Bryson (1961) analyzed wind and surface drift data from Lake Mendota and have shown that at a wind speed below about 19 fps, the average wind factor was about 1.3 percent. However, above this wind velocity, which they termed the critical wind velocity, the wind factor assumed a nonlinear distribution with some reduction in absolute magnitude. In a recent article, Shemdin (1973) observed that the surface drift can be taken as about 3.4 percent of the wind velocity measured at a height of 32.8 feet above the water surface.

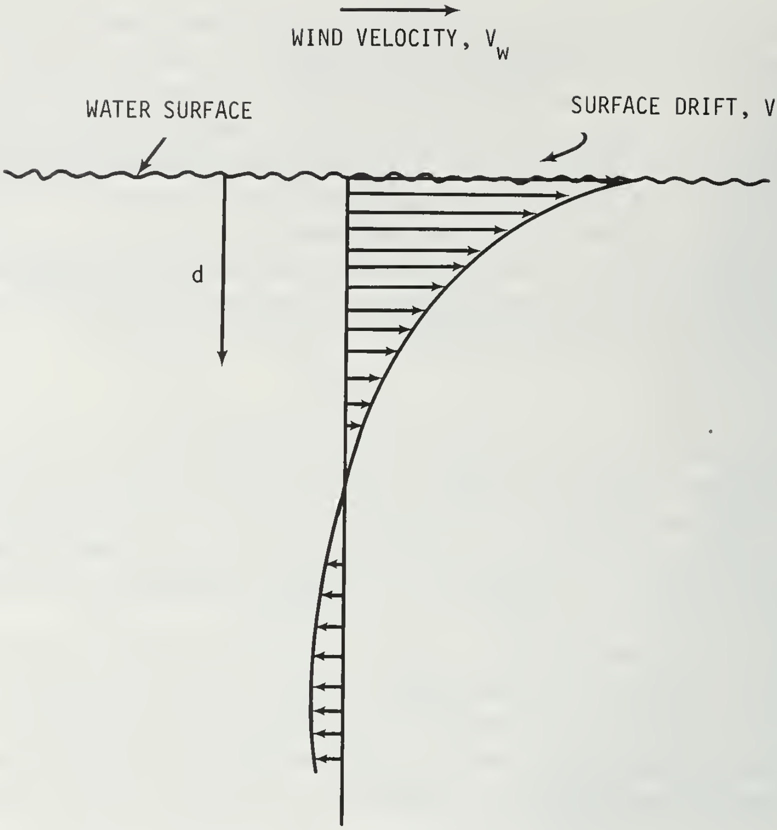


Figure 45. Schematic of surface drift and flow profile

Wind-Generated Current Profiles in Water. The surface drift that is produced by wind is generally accompanied by movement of water below the water surface. The magnitude of flow velocity near the water surface is high compared with the flow velocity at a given depth below the surface. This reduction of flow velocity is very sharp and may attain a value of zero at some depth after which a return flow may exist. Figure 45 shows a sketch of the surface drift and flow profile below the water surface for a hypothetical wind condition.

Bye (1965) collected field data on wind-generated current profiles from Lough Neagh in Northern Ireland. The total depth of water was 32.8 feet, wind velocity varied from about 23 to 26 fps, and the fetch was about 9 miles. He used weighted floats about 1-inch square in lengths varying from 1 inch to about 3 feet to measure the velocity of water at different depths. Using the concept of zero resultant drag on each float, he deduced the velocity profiles from a series of floats of different lengths. Bye's data indicated that the velocity distribution was logarithmic and could be expressed by the relationship given below:

$$V_s - V_d = [V_*/\kappa] \ln (z/z_{ow})$$

where V_d is the velocity of water at a depth equal to d, V_* is the water shear velocity, and z_{ow} is the water roughness parameter. Shemdin (1973) collected extensive data on current profiles from a laboratory facility and also concluded that the current profile can be approximated by a logarithmic distribution similar to this equation. Shemdin also observed some return flow in their wind-water tunnel facility similar to the sketch shown in figure 45.

General Circulation Patterns in the Chain of Lakes. As mentioned earlier, extensive localized circulation data were collected from different lakes in the Chain. These data are presented as a group for each site. Figure 46 shows the locations of all the areas where specific circulation data were collected.

Fox River Entrance to Grass Lake. The flow pattern data at this location were collected at various times during 1975. Since only one semipermanent station could be located here (station 30, figure 46), stadia distance and bearing angle were used to locate the float in the water. Figure 47 shows the circulation pattern for May 23, 1975. Here the flow pattern varies as the direction of the wind changes and a strong effect of wind is clearly visible. Figure 48 shows the flow patterns for July 15 and October 8, 1975. Because the morning of October 8 was almost calm, some flow pattern data were collected near the middle of the lake. It appears that during such a calm period, the Fox River water flows downstream toward the Grass Lake Bridge outlet. Figure 49 shows the flow pattern for November 18, 1975. The effect of wind on the flow pattern is clearly visible.

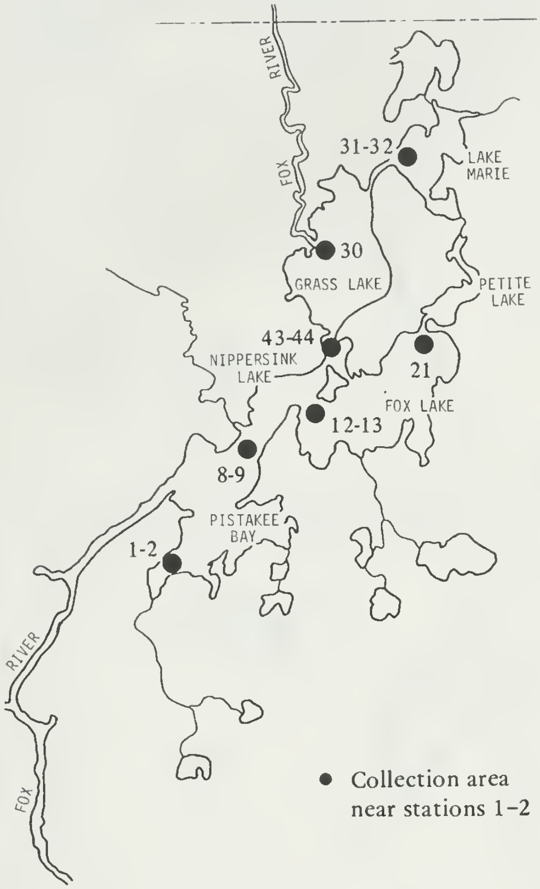


Figure 46. Circulation data collection areas

Flow Pattern from Grass Lake to Lake Marie. Stations 31 and 32 (figure 46) were used to collect the flow pattern data at this location. In general, water was found to be flowing from Grass Lake into Lake Marie. However, on a number of occasions, it was observed that the wind affected the pattern of flow, changed the direction of the floats, and the water followed a path somewhat resembling the resultant of the inflow and wind direction.

Figure 50 shows the flow pattern for May 21, 1975. The 12- and 24-inch deep vanes indicate the formation of a long shore current along the northern shore of Lake Marie. Figure 50 also shows the flow pattern on July 15, 1975, when the effect of the wind was also predominant. Figure 51 shows the flow pattern for October 7 and October 10, 1975. On October 10, the vanes were moved inside Lake Marie by a strong westerly wind.

The flow patterns on November 18 and 21, 1975, are shown in figure 52.

Entrance to Fox Lake from Petite Lake. Permanent stations 21 and 22 were used to collect the flow pattern data. Data were collected only on May 21, 1975. Extreme difficulty in the collection of the data at this location precluded any additional work for this area of the lake. Figure 53 shows the flow pattern for this date, and the effect of wind is definitely visible.

Flow Pattern below Grass Lake Road Bridge. In general, water flows downstream at this particular location. Once in a while a strong southerly wind would induce some local change in the flow pattern, but the overall downstream flow pattern remained the same.

Figure 54 shows the flow pattern on May 22 and July 16, 1975. The southerly wind on

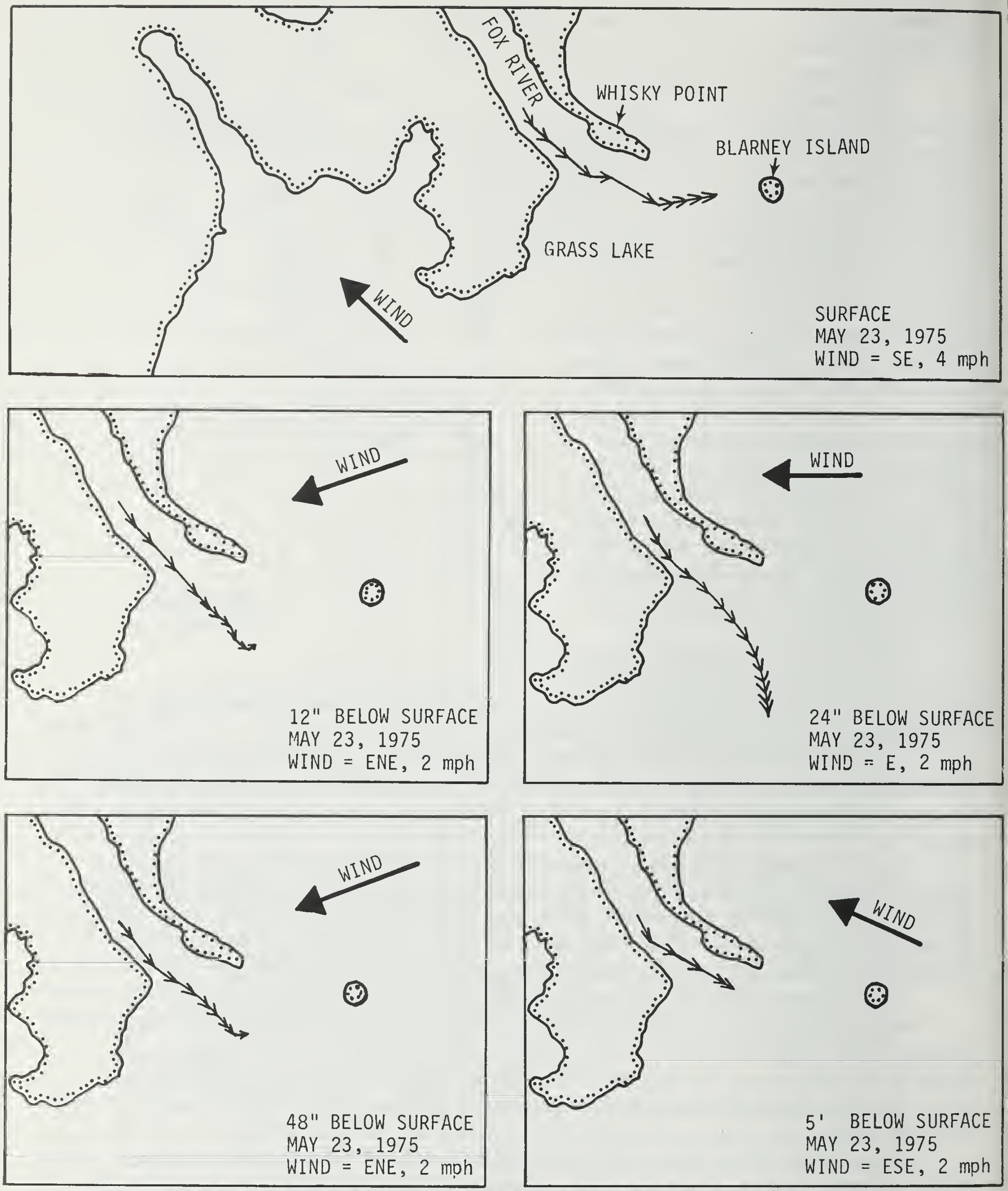


Figure 47. Flow pattern at the entrance of Fox River to Grass Lake for May 23, 1975

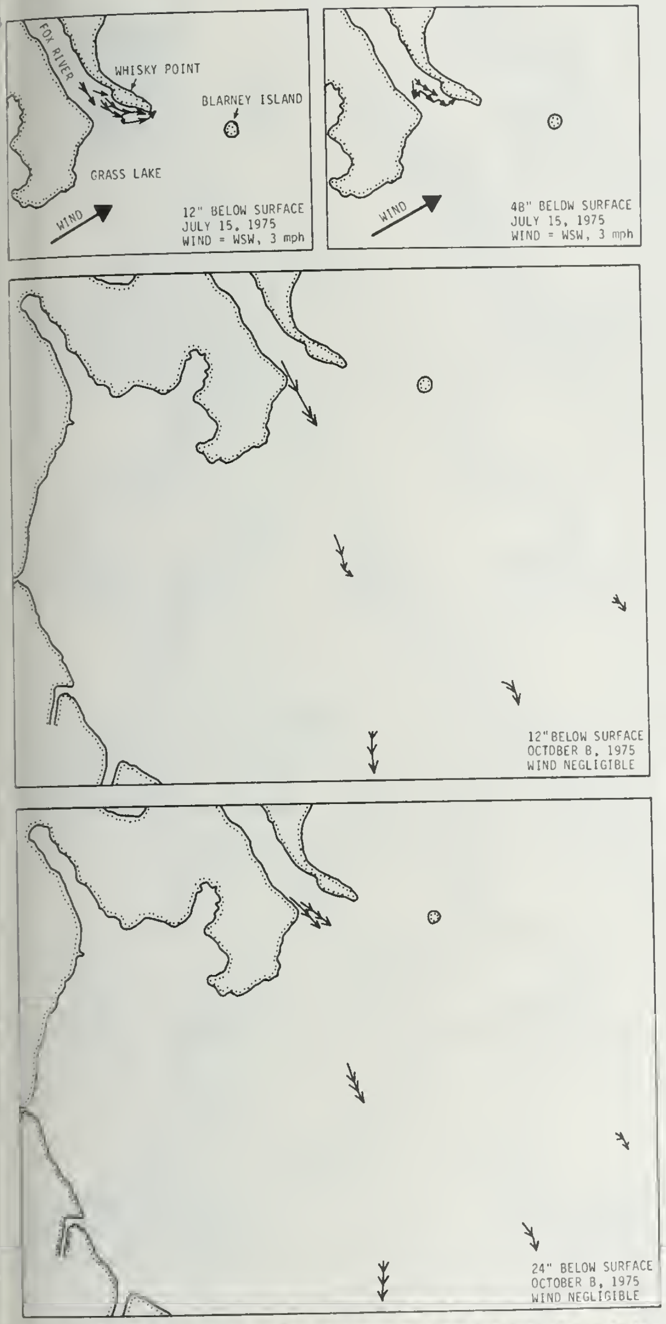


Figure 48. Flow pattern at the entrance of Fox River to Grass Lake for July 15, and October 8, 1975

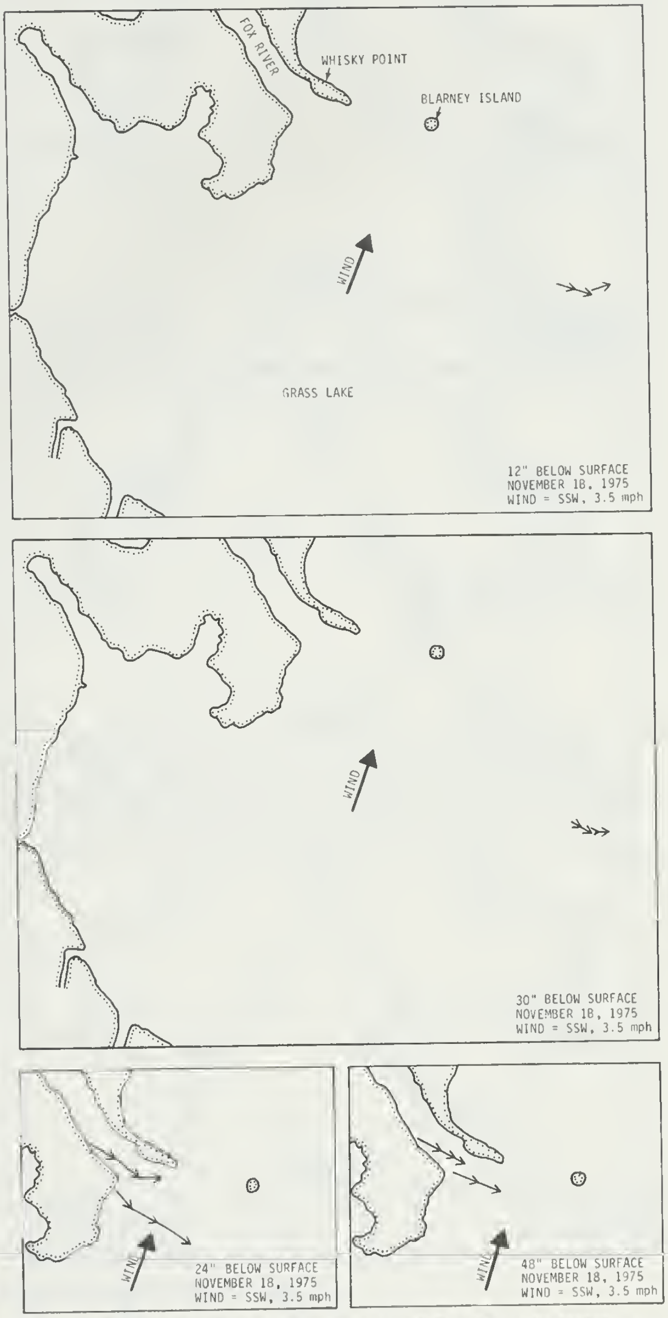


Figure 49. Flow pattern at the entrance of Fox River to Grass Lake for November 18, 1975

July 16 affected the 12-inch deep vanes by moving them toward the bridge, but the 24-inch deep vanes moved in the downstream direction. The flow patterns for October 7 and November 19 are shown in figure 55.

Flow Pattern between Fox Lake and Nippersink Lake. These data were collected between stations 12 and 13 (figure 46). Flow patterns on May 20 and 22, and on July 16, 1975, are shown in figure 56. In general, water flows from the Fox Lake into Nippersink Lake with some deviation of the flow path because of wind movement.

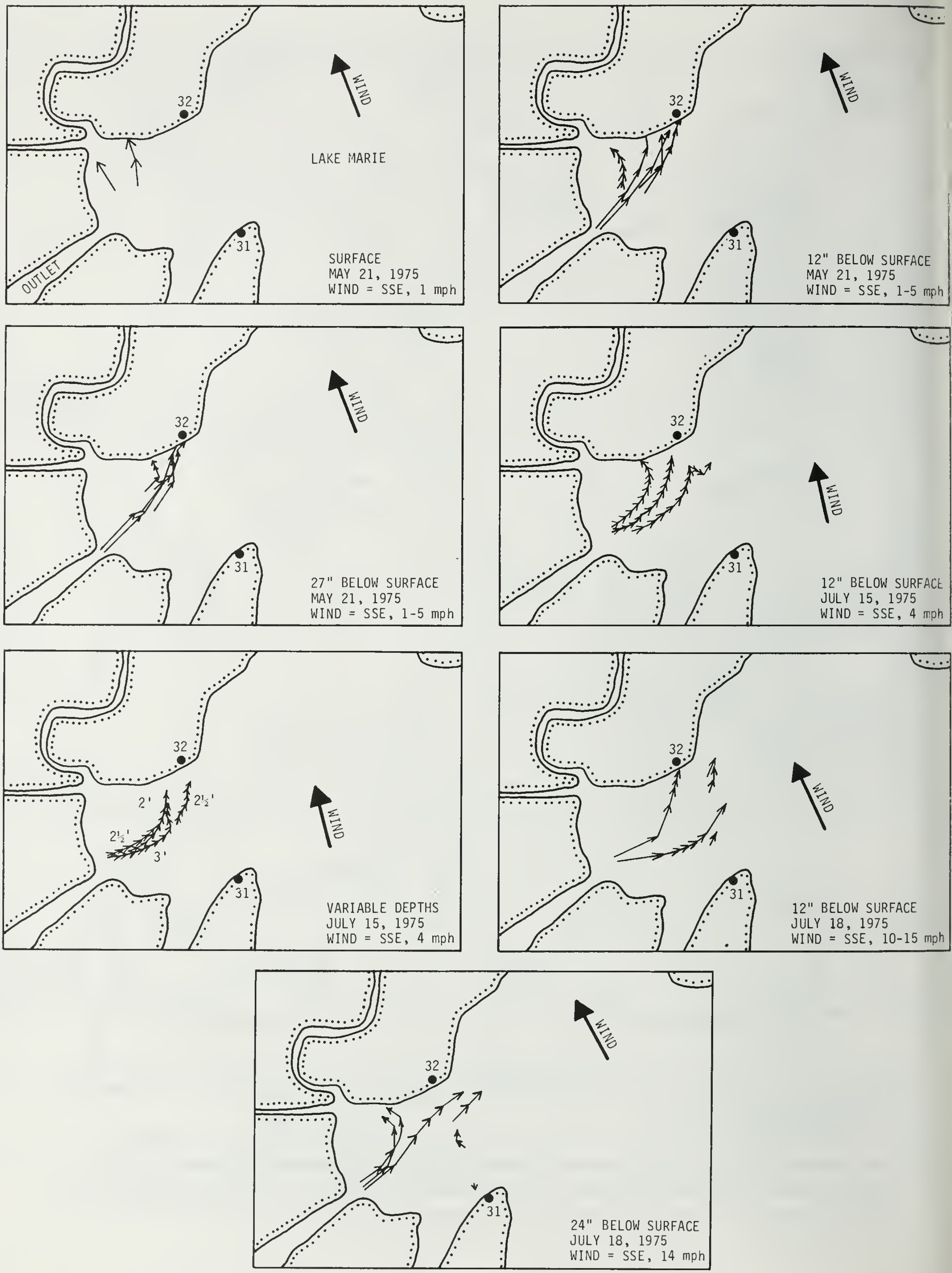


Figure 50. Flow pattern from Grass Lake to Lake Marie for May 21, July 15, and July 18, 1975

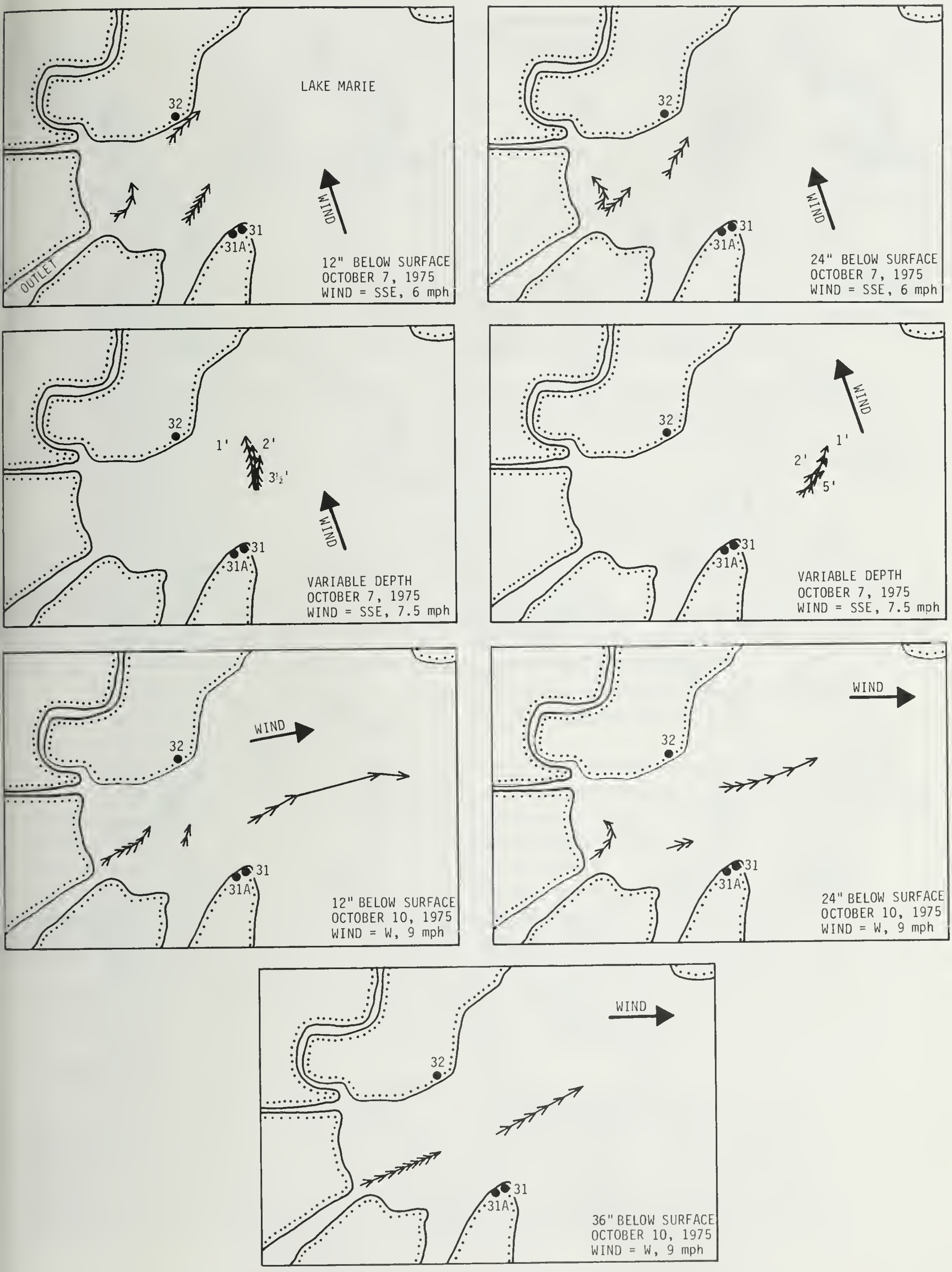


Figure 51. Flow pattern from Grass Lake to Lake Marie for October 7 and October 10, 1975

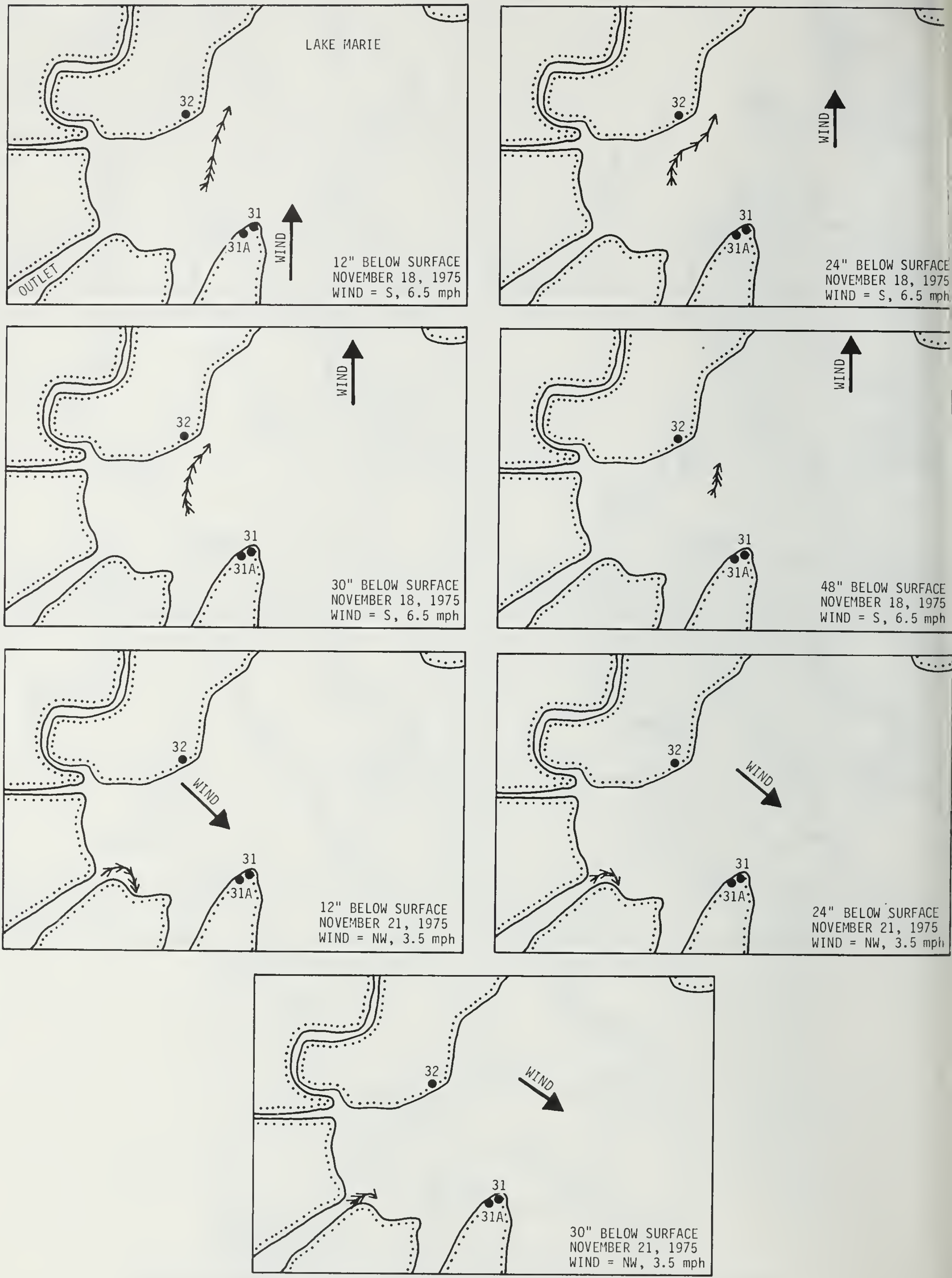


Figure 52. Flow pattern in Lake Marie near the entrance from Grass Lake for November 18 and November 21, 1975

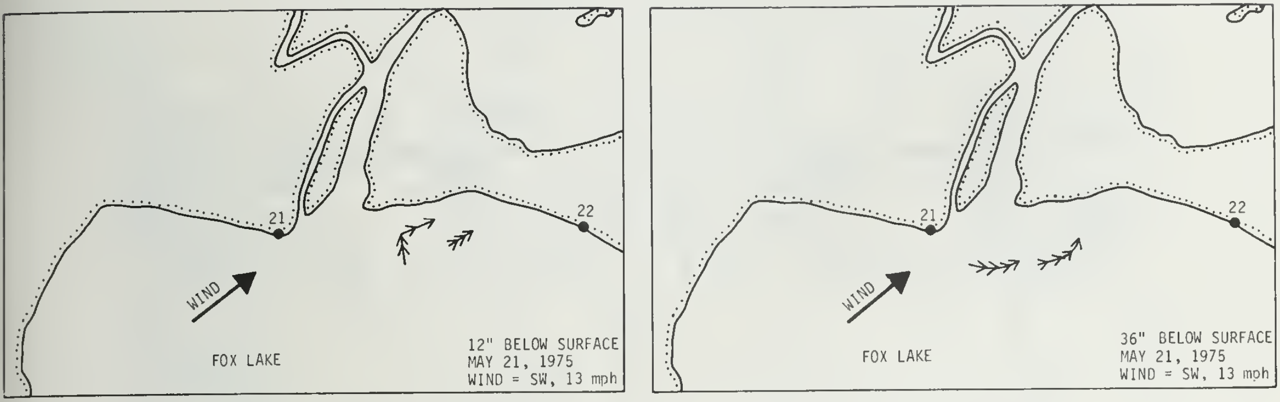


Figure 53. Flow pattern in Fox Lake at the entrance from Petite Lake for May 21, 1975

Figure 57 shows the flow pattern on October 8, 1975. Presence of a moderate wind from the east-southeast has modified the flow pattern with the development of a long shore current along the south shore of Fox Lake. Figure 57 shows a change in the flow pattern for November 19, caused by a change in wind direction.

Flow Pattern Downstream of Highway 12 Bridge. Stations 8 and 9 (figure 46) were used to collect data at this location. Water flows in the downstream direction below the highway bridge. When this flow reaches Pistakee Lake, the presence of southerly winds generally deflects the flow and moves it in a circular route before it finally moves on downstream. Nett's Island acting as a barrier also modified the flow pattern.

Figure 58 shows the measured and probable flow patterns for May 15, 1975. Effects of southerly wind and Nett's Island are clearly visible. Figure 58 also shows the flow pattern for July 17, 1975. The flow pattern for October 9, 1975, is shown in figure 59.

Flow Pattern in Pistakee Bay. Extensive flow data from Pistakee Bay were collected with the use of stations 1 and 2 (figure 46). The inflow to Pistakee Bay from Lily Lake Drain can be considered negligible.

Figure 60 shows the flow pattern for May 15, 1975. The surface floats were basically moving in the direction of the wind. The movement of the 12-inch deep floats close to the western shore definitely indicated the presence of a long shore current. Figure 60 also shows the flow pattern for May 16 at the surface and 12 inches below surface. Wind was blowing from the east-northeast and basically the upper layer of water was moving in the same direction. However, 5 feet below the water surface, water was moving in the opposite direction indicating the presence of some type of return flow (figure 61). It is interesting to note that 10 feet below the water surface the water was moving in the direction of the wind.

The flow pattern for July 17 in figure 61 shows the upper layer of the water moving in the direction of the wind, whereas 5 feet below the surface water was moving in the opposite direction. The presence of a long shore current can be seen in this figure.

Figures 62 and 63 show the circulation patterns for October 9, 1975. Some deviations of water movement are present.

General Observations Regarding Circulation Patterns. The circulation patterns in all of the lakes in areas of negligible inflows were generally governed by the wind. The direction and magnitude of the wind played a very important role in determining the flow patterns. In zones of significant inflow, such as the Fox River inflow (figures 47–49) or the inflow from Grass Lake to Lake Marie (figures 50–52), as soon as the diffusion of the inflow jets reduced the flow velocity, the wind-induced circulation patterns dominated the

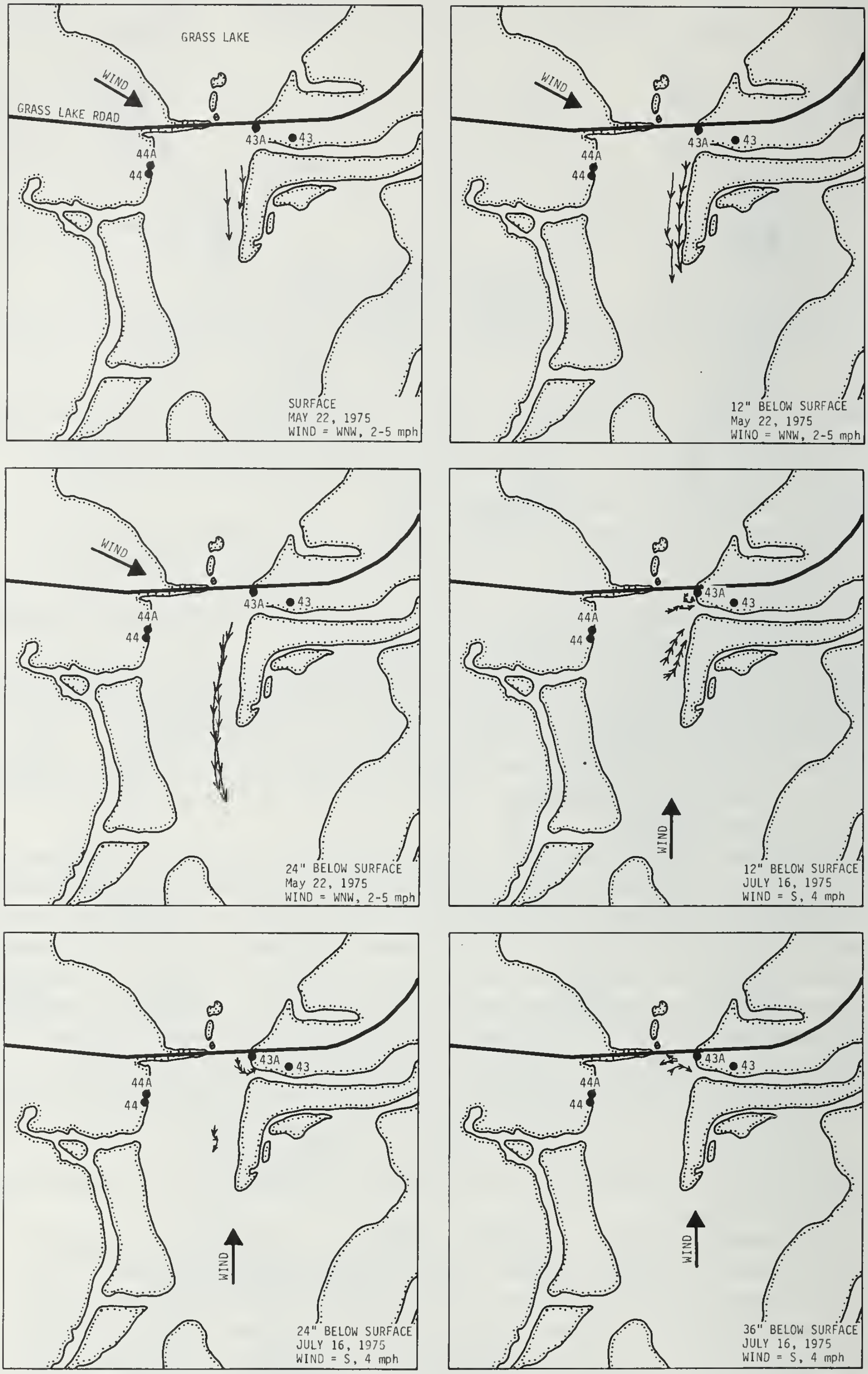


Figure 54. Flow pattern below Grass Lake Road for May 22 and July 16, 1975

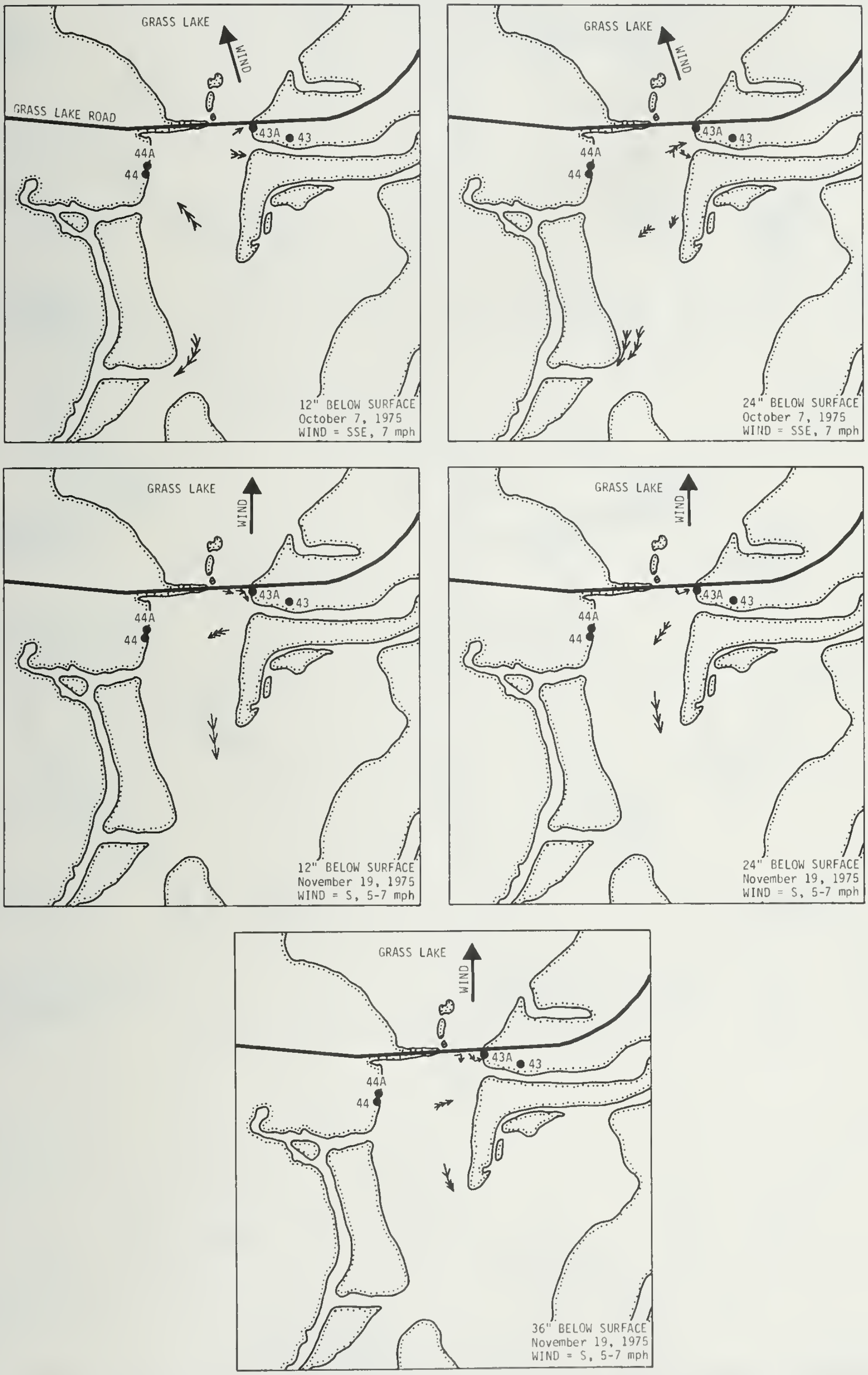


Figure 55. Flow pattern below Grass Lake Road for October 7 and November 19, 1975

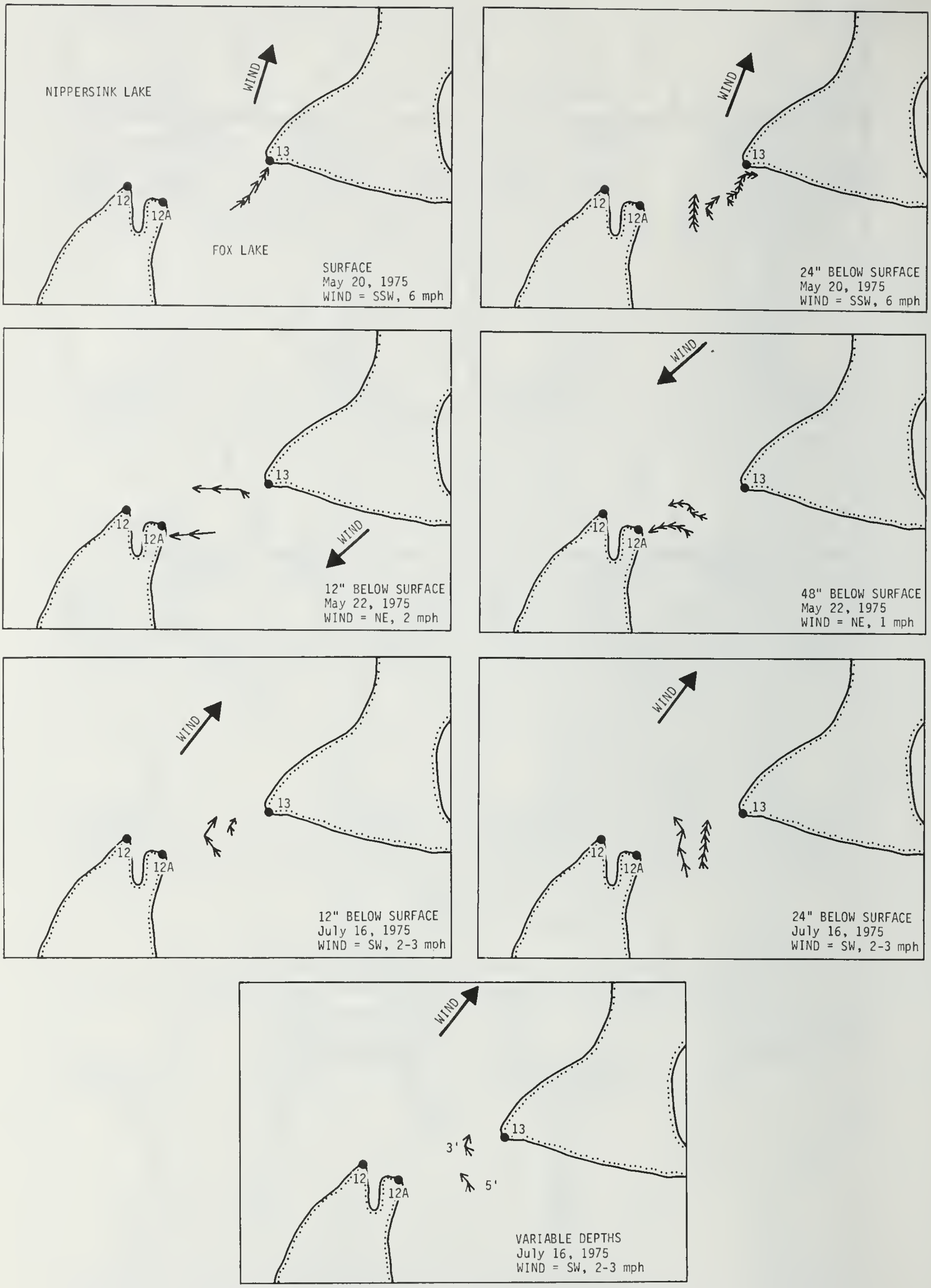


Figure 56. Flow pattern between Fox Lake and Nippersink Lake for May 20, May 22, and July 16, 1975

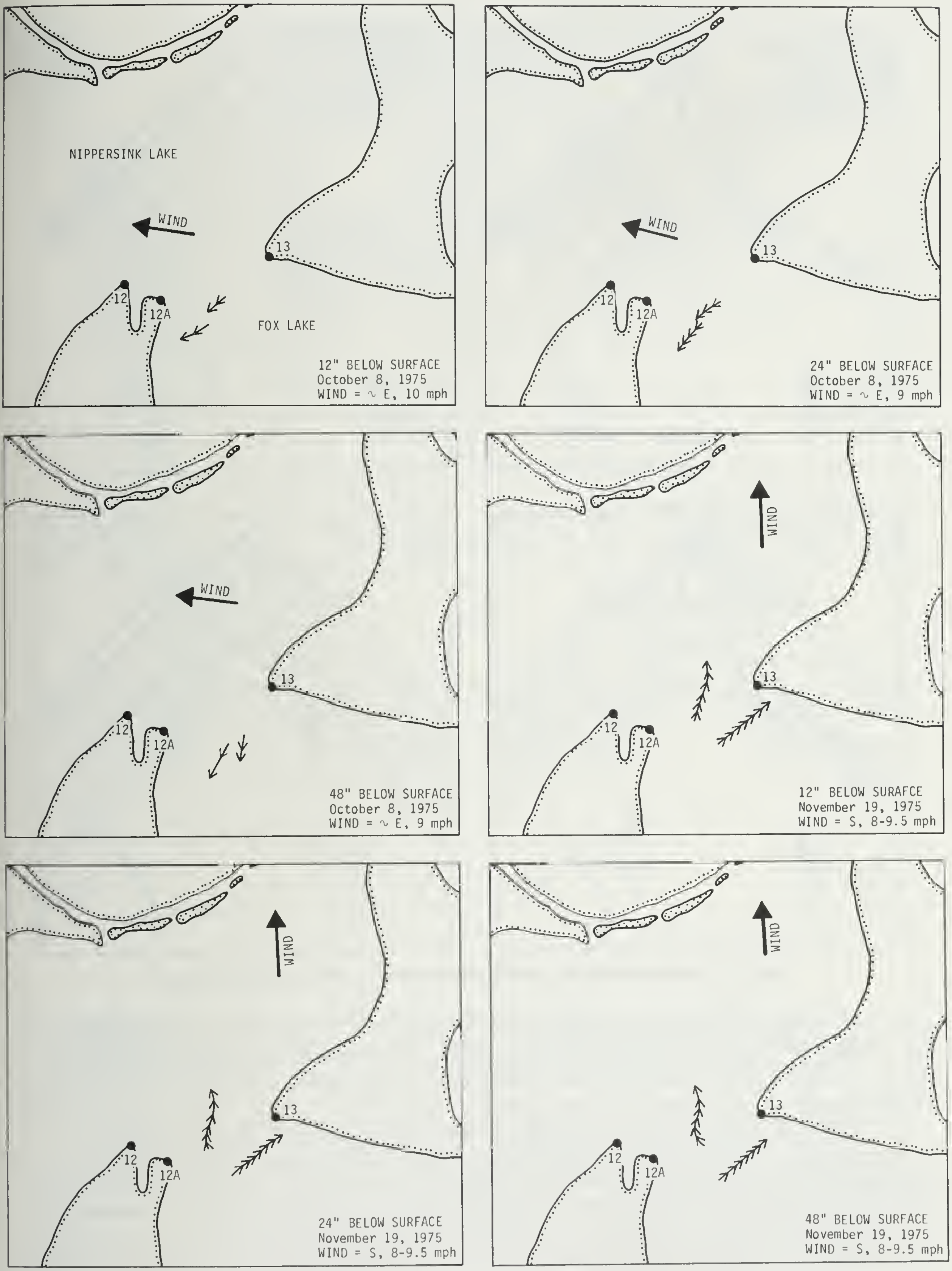


Figure 57. Flow pattern between Fox Lake and Nippersink Lake for October 8 and November 19, 1975

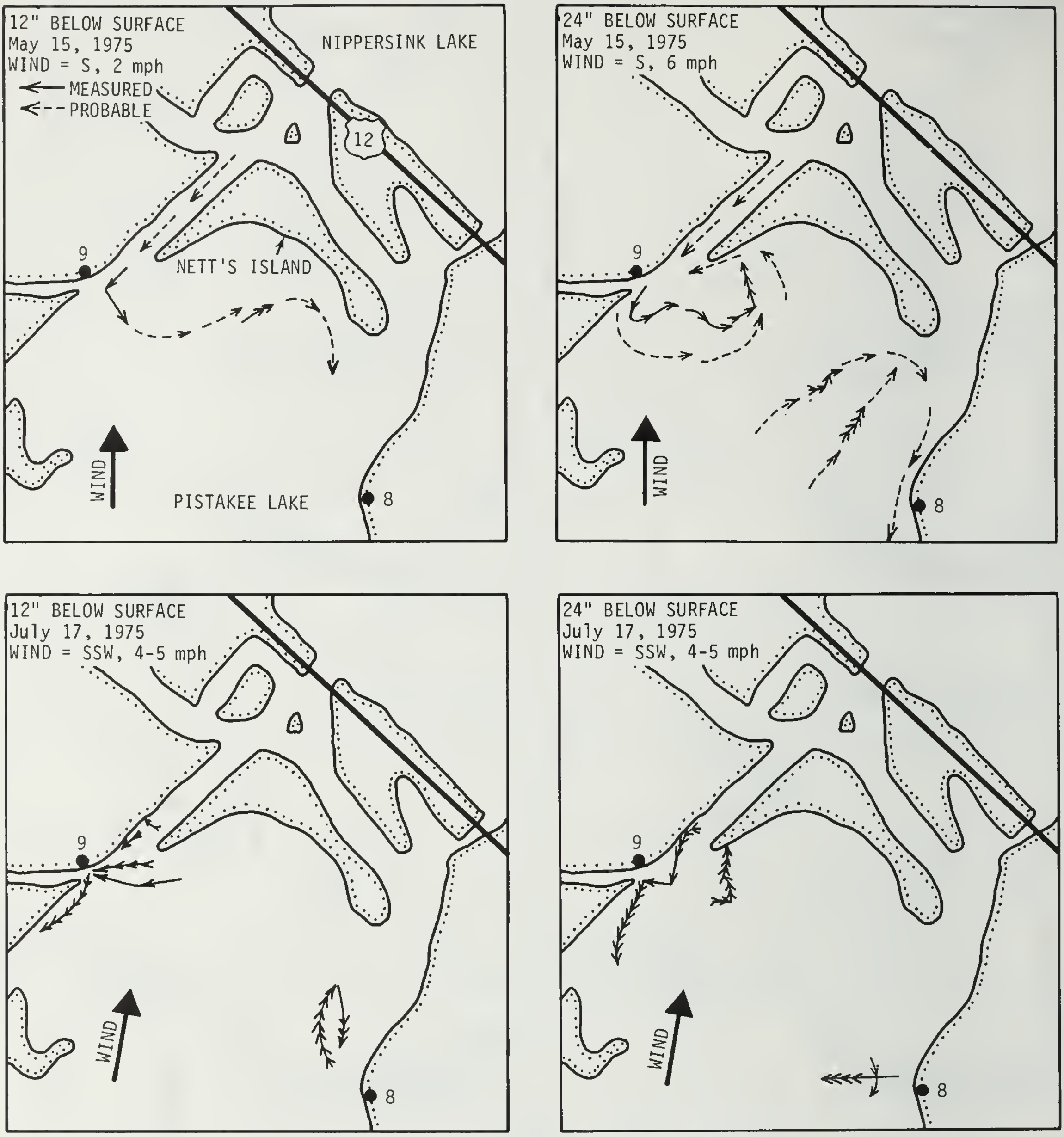


Figure 58. Flow pattern downstream of Highway 12 Bridge for May 15 and July 17, 1975

general movement of the water. Figures 50–52 also show that the velocity vector entering Lake Marie from Grass Lake was deflected as a result of the presence of a moderate southerly wind. During the whole process of data collection, it was repeatedly observed that the circulation pattern is a function of the wind velocity and direction.

Measured Current Profile. Generally, as described earlier, three sets of floats with cross vanes were dropped to various depths and followed simultaneously from two fixed shore stations, and these data were used to compute the flow velocity at different depths. Figure 64 shows some typical current profiles plotted on semilogarithmic paper. Data from three different locations are plotted in this figure. In general, these vertical current profiles follow logarithmic distributions as postulated in Bye's equation *(page 68).* Figure 65 shows

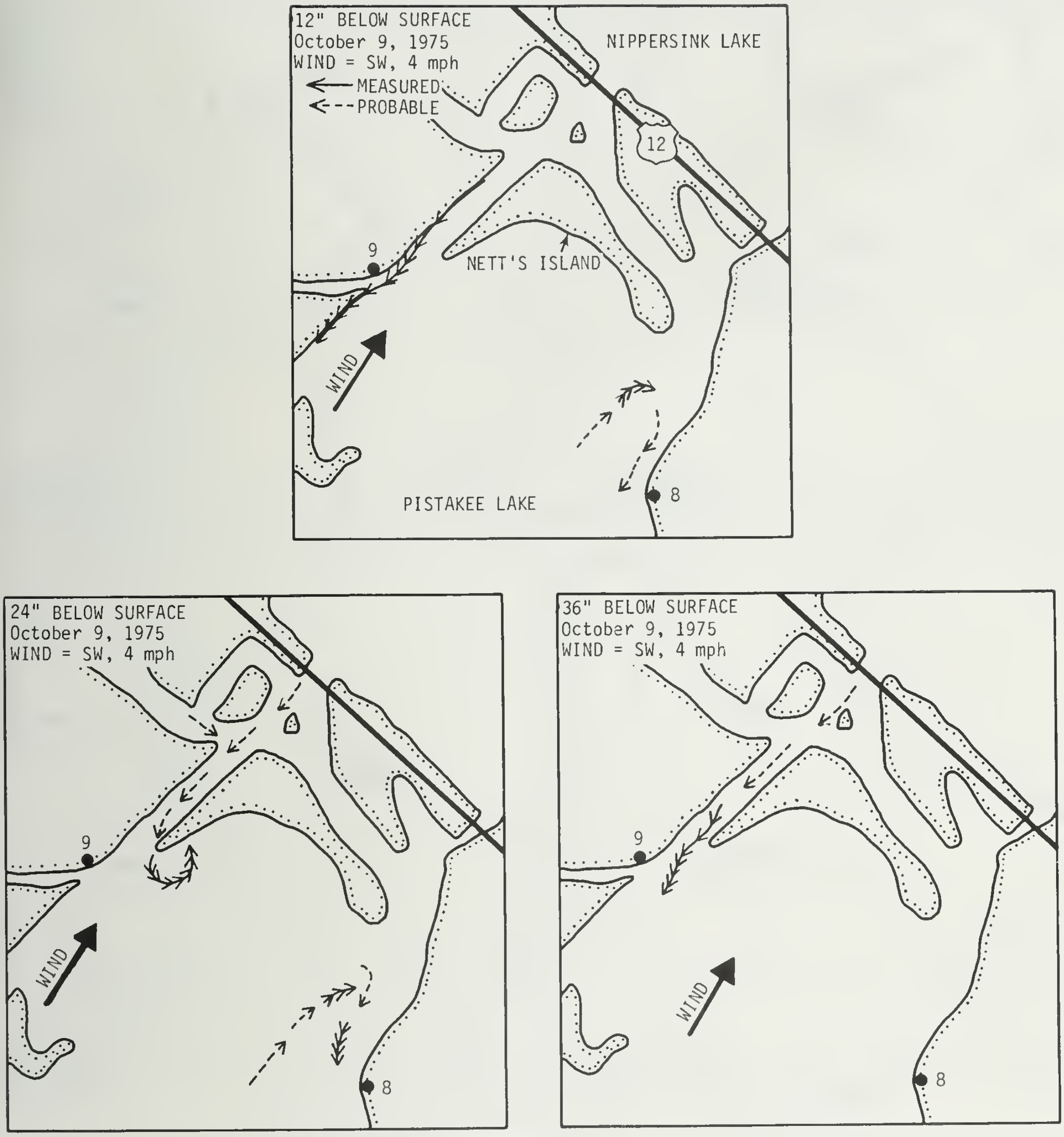


Figure 59. Flow pattern downstream of Highway 12 Bridge for October 9, 1975

the vertical current profile plotted on coordinate paper. Data were collected on July 16, 1975, between Fox and Nippersink Lakes. The shape of this current profile is similar to the one shown in figure 45. Basically, the flow velocity near the water surface is high and velocity decreases with depth.

Data collected from Pistakee Bay indicated the presence of return flow for some wind conditions, as exemplified in figures 60 and 61. The vertical current profile for May 16, 1975, is shown in figure 66. On this particular day water near the surface moved in the same direction as the wind, at about 5 feet below the surface the water was moving in the opposite direction, and somewhere below 10 feet the water was again moving in the direction of the wind. This indicated the very complex nature of the flow patterns. It must be pointed out

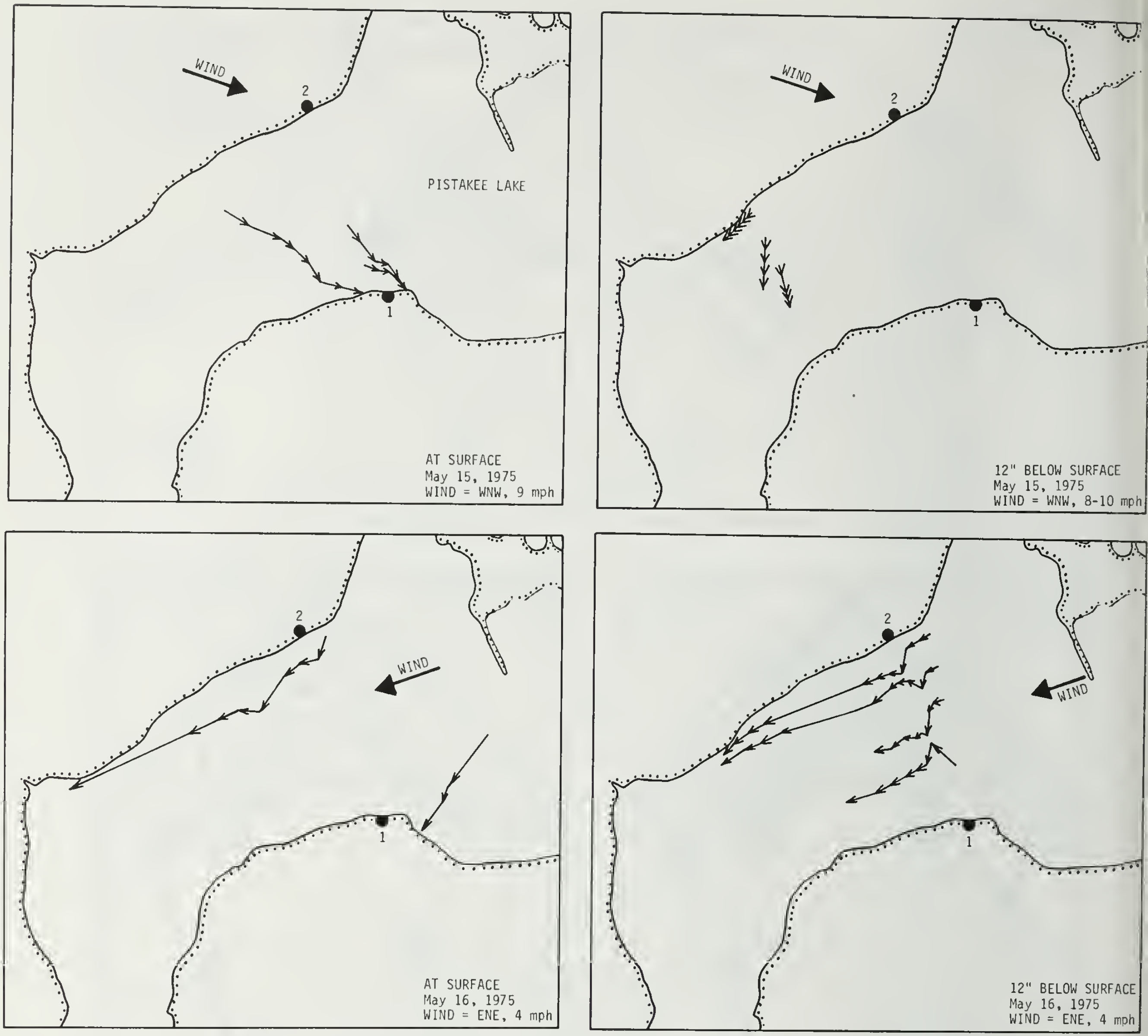


Figure 60. Flow pattern in Pistakee Bay for May 15 and May 16, 1975

that the magnitude of the velocities is very small and only long periods of observation confirmed these movements.

Therefore, it appears that in most cases the wind-generated current profile is logarithmic in nature and that a return flow may exist below the water surface, though the absolute magnitude of this flow may be very small.

Available published data related to surface drift and wind factor have already been discussed. Some of the data collected in the Chain of Lakes on surface drift are given in table 16. The wind factor, defined as the ratio of surface drift to wind velocity, varied from 2 to 11 percent. However, the higher values of wind factor at stations 8-9, 31-32, and 43-44 do not represent the effect of wind-induced surface current because the influence of the inflow is very strong at these locations. For the other stations, the wind factor varied from 2 to 7 percent.

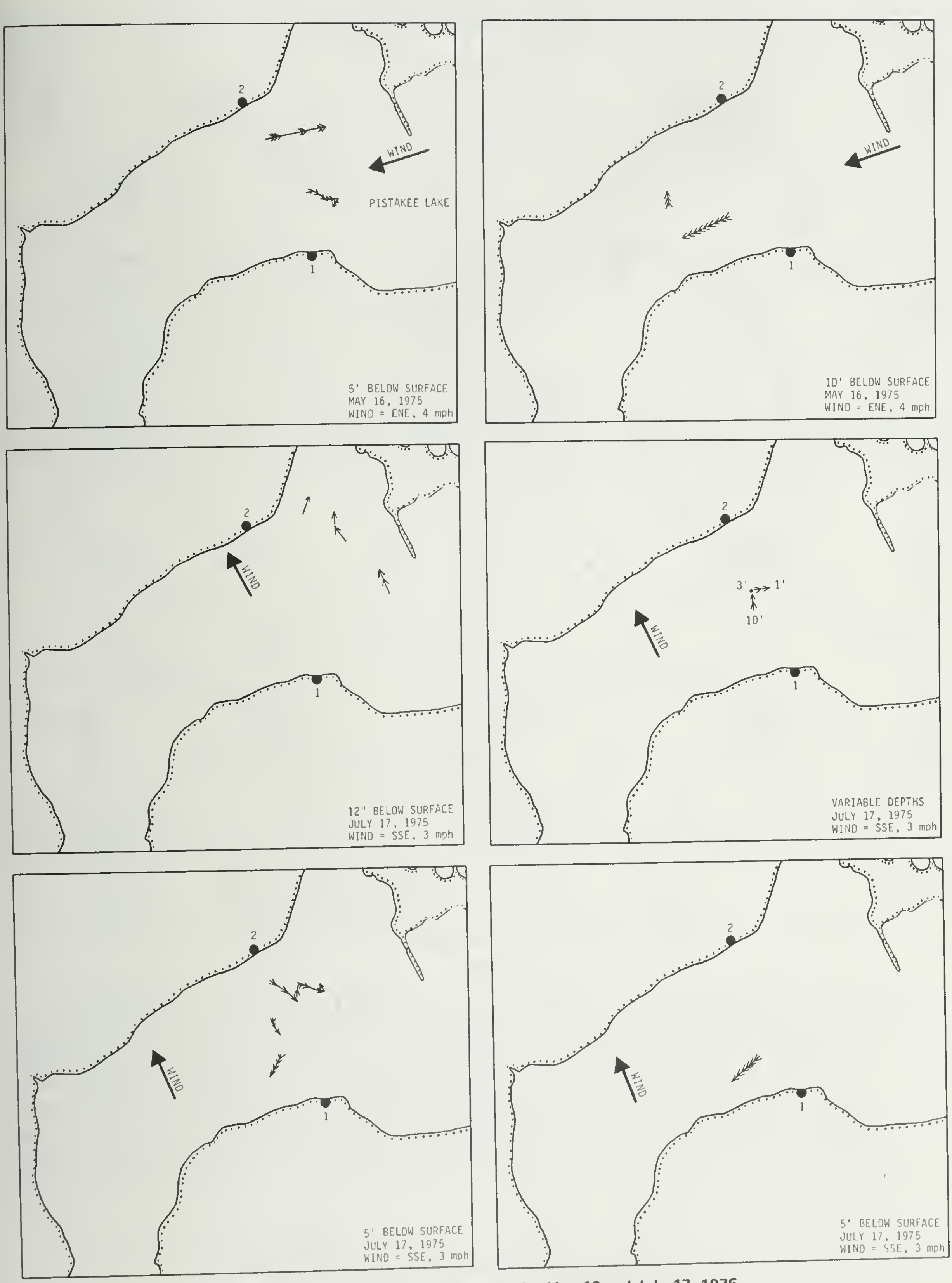


Figure 61. Flow pattern in Pistakee Bay for May 16 and July 17, 1975

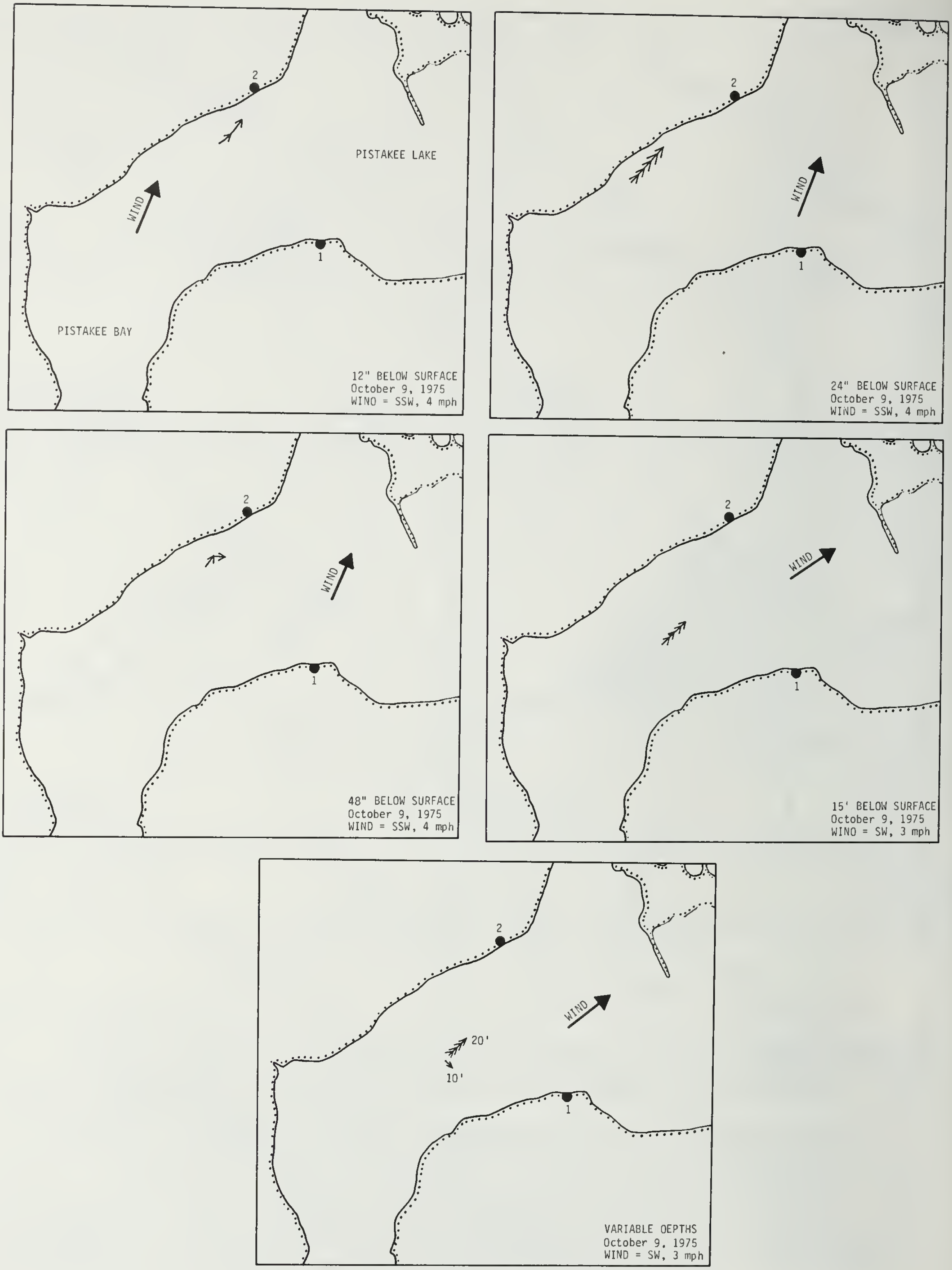


Figure 62. Flow pattern in Pistakee Bay for October 9, 1975

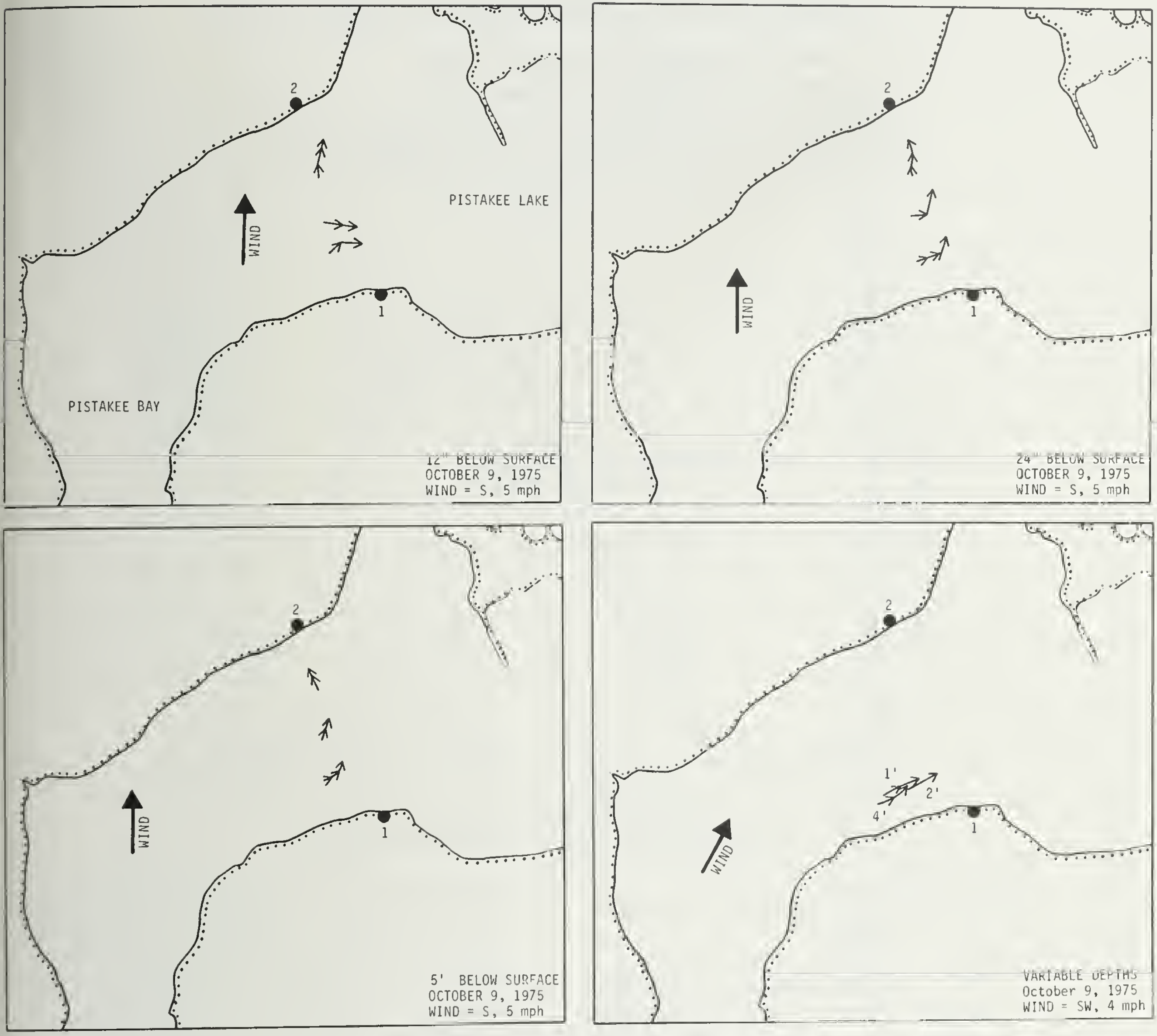


Figure 63. Flow pattern in Pistakee Bay for October 9, 1975

Comparison of Theoretical Circulation Patterns and Field Data. A considerable amount of theoretical and analytical work has been done by various investigators on circulation patterns in large lakes. Methods such as finite element, finite difference, method of characteristics, and others were utilized to solve the equation of momentum transport. Recently Song (1976) using the finite element method proposed by Gallagher et al. (1973) computed a theoretical circulation pattern for the Pistakee Bay area of the Chain of Lakes. The incompressible form of the momentum transport equation used is given in vector form (Liggett and Hadijtheodorou, 1969) as follows:

$$\frac{\partial \vec{v}}{\partial t} + (\vec{v}\cdot\vec{v}) + \vec{F} + \frac{1}{\rho}\vec{\nabla} p - \vec{g} - \eta\nabla^2 v = 0$$

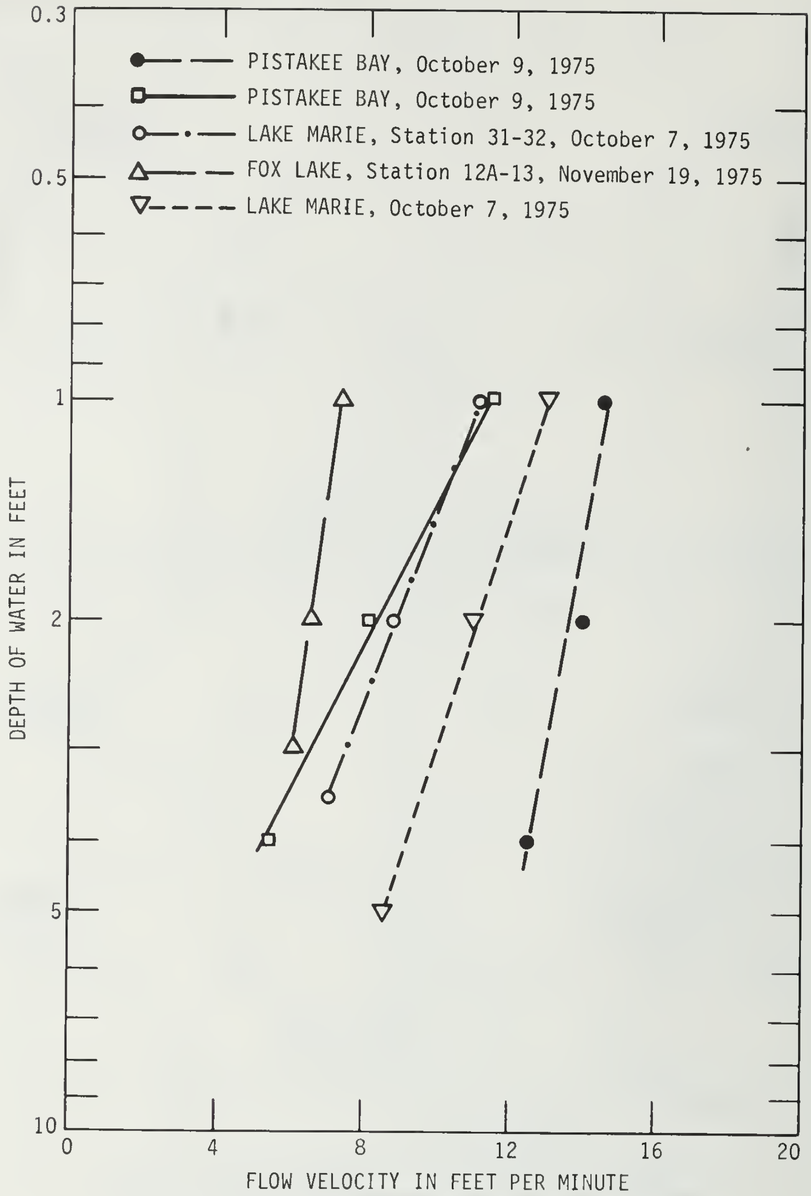


Figure 64. Typical vertical current profile (logarithmic)

where $\vec{v}$ is the water velocity, $\vec{F}$ is the Coriolis force which accounts for the earth's rotation on the flow, $\vec{g}$ is the gravity factor, ρ is the fluid density, η is the eddy viscosity, and p is the pressure. This equation was simplified for a shallow lake with hydrostatic pressure distribution under the influence of steady-state wind conditions. The Coriolis parameter was assumed to be constant and the Rossby number (ratio of inertial forces to rotational forces) was taken to be small. The above equation can thus be simplified to

$$\vec{F} - \vec{g} = -\frac{1}{\rho}\vec{\nabla}\rho + \eta\nabla^2\vec{V}$$

This equation and the finite element method as proposed by Gallagher et al. (1973) were utilized by Song (1976) with appropriate boundary conditions to obtain circulation patterns

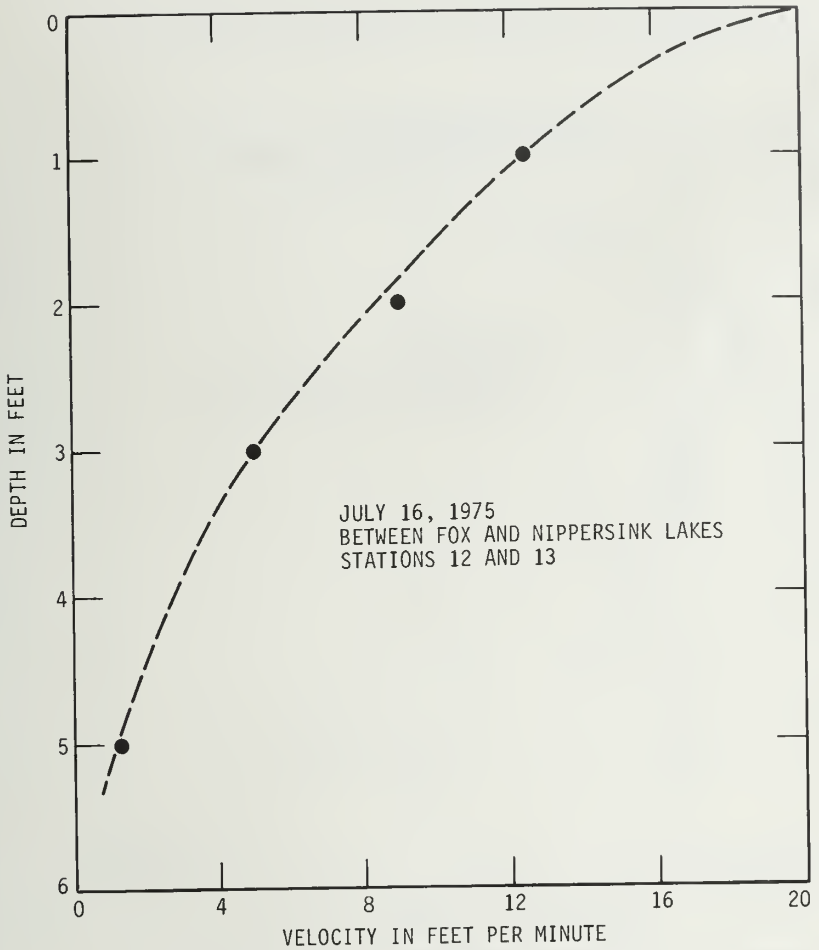


Figure 65. Current profile in Fox Lake on July 16, 1975

in the Pistakee Bay area for some known wind conditions. A number of Calcomp plots were obtained by varying the numerical value of the eddy viscosity, η. Figures 67–70 compare some of the typical computer plots with the observed field data. Correlations between theory and the field data appear to be very good. The magnitude and direction of the flow velocities obtained in the Calcomp plots follow very closely the flow pattern data obtained from Pistakee Bay.

This analysis indicates that the wind-generated circulation patterns in natural lakes can be predicted to some extent by using the analytical and mathematical formulations that have already been developed. One area where further work is needed is the proper determination of the numerical value of eddy viscosity η for actual field conditions.

Table 16. Wind Factor in the Chain of Lakes

Date of data collection	*Stations*	*Wind factor (%)*	*Lake*
May 15, 1975	8-9	10.2*	Pistakee
		9.1*	Pistakee
May 21, 1975	31-32	5.7	Marie
		7.2*	Marie
May 20, 1975	12-13	2.1	Between Fox and Nippersink
		3.3	
May 22, 1975	43-44	11.8*	Below Grass Lake Road Bridge
		7.5*	
May 15, 1975	1-2	2.7	Pistakee Bay
	1-2	2.1	Pistakee Bay
	1-2	2.0	Pistakee Bay
May 16, 1975	1-2	7.1	Pistakee Bay
		5.4	Pistakee Bay

*Affected by inflow
Note: Wind factor = (Surface drift/wind velocity) x 100

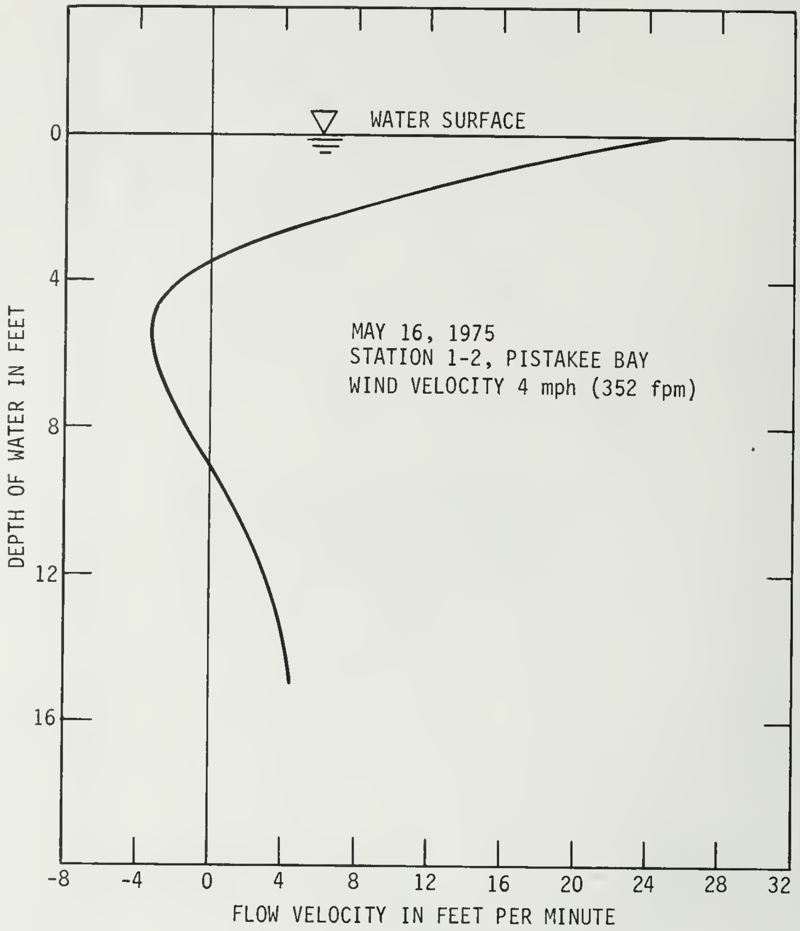


Figure 66. Vertical current profile in Pistakee Bay on May 16, 1975

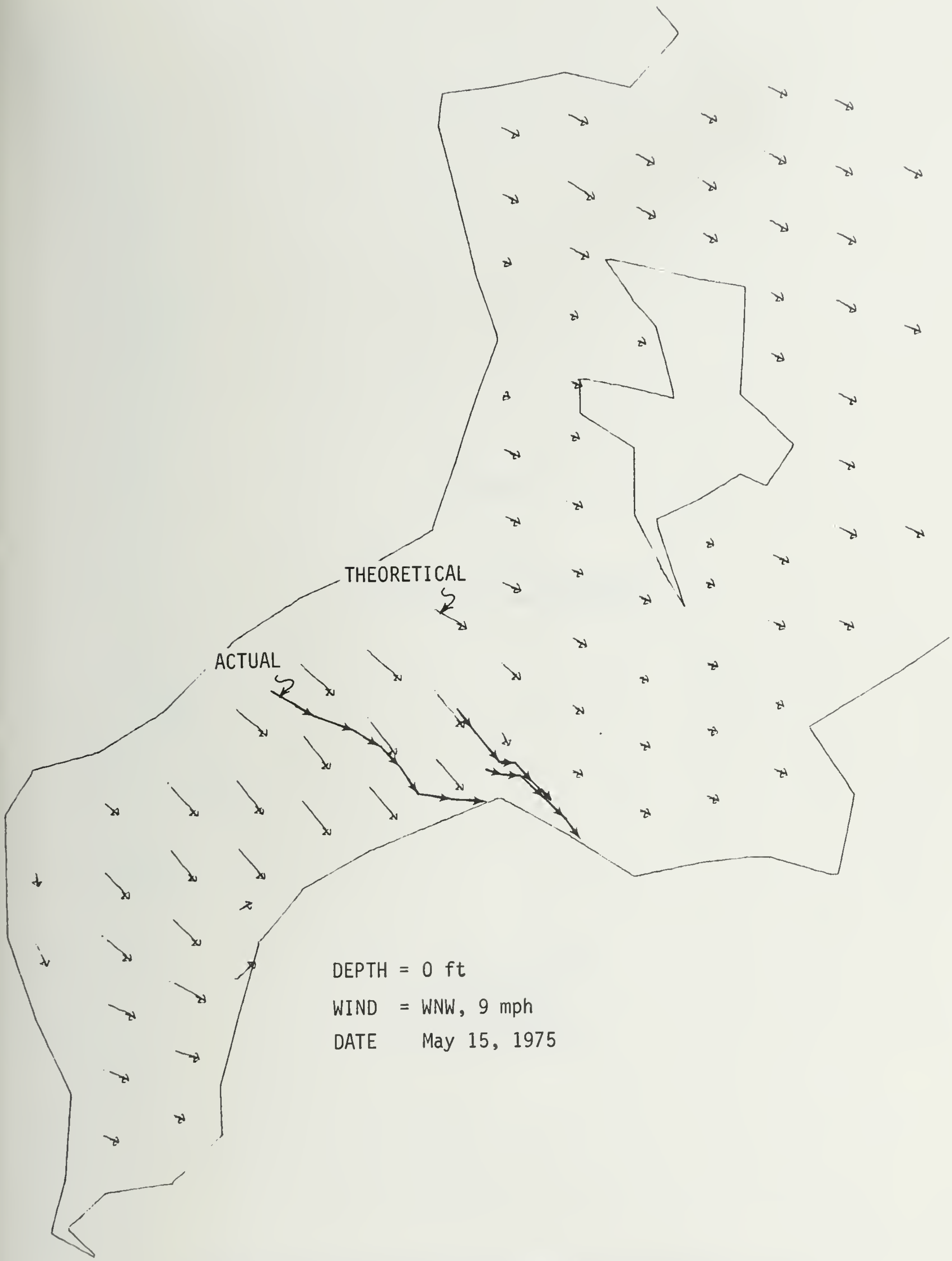


Figure 67. Theoretical and actual circulation patterns in Pistakee Bay

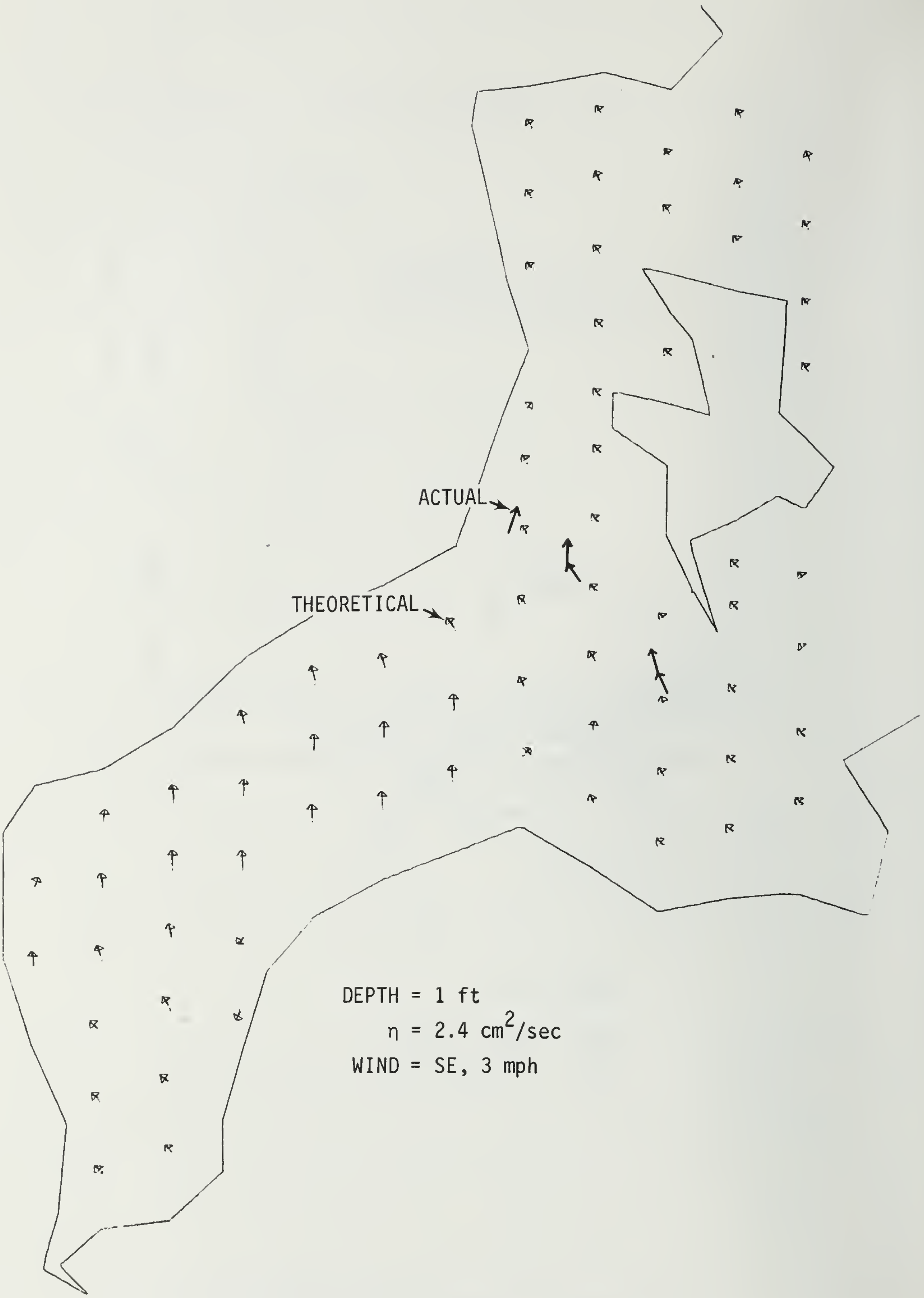


Figure 68. Theoretical and actual circulation patterns in Pistakee Bay, July 17, 1975

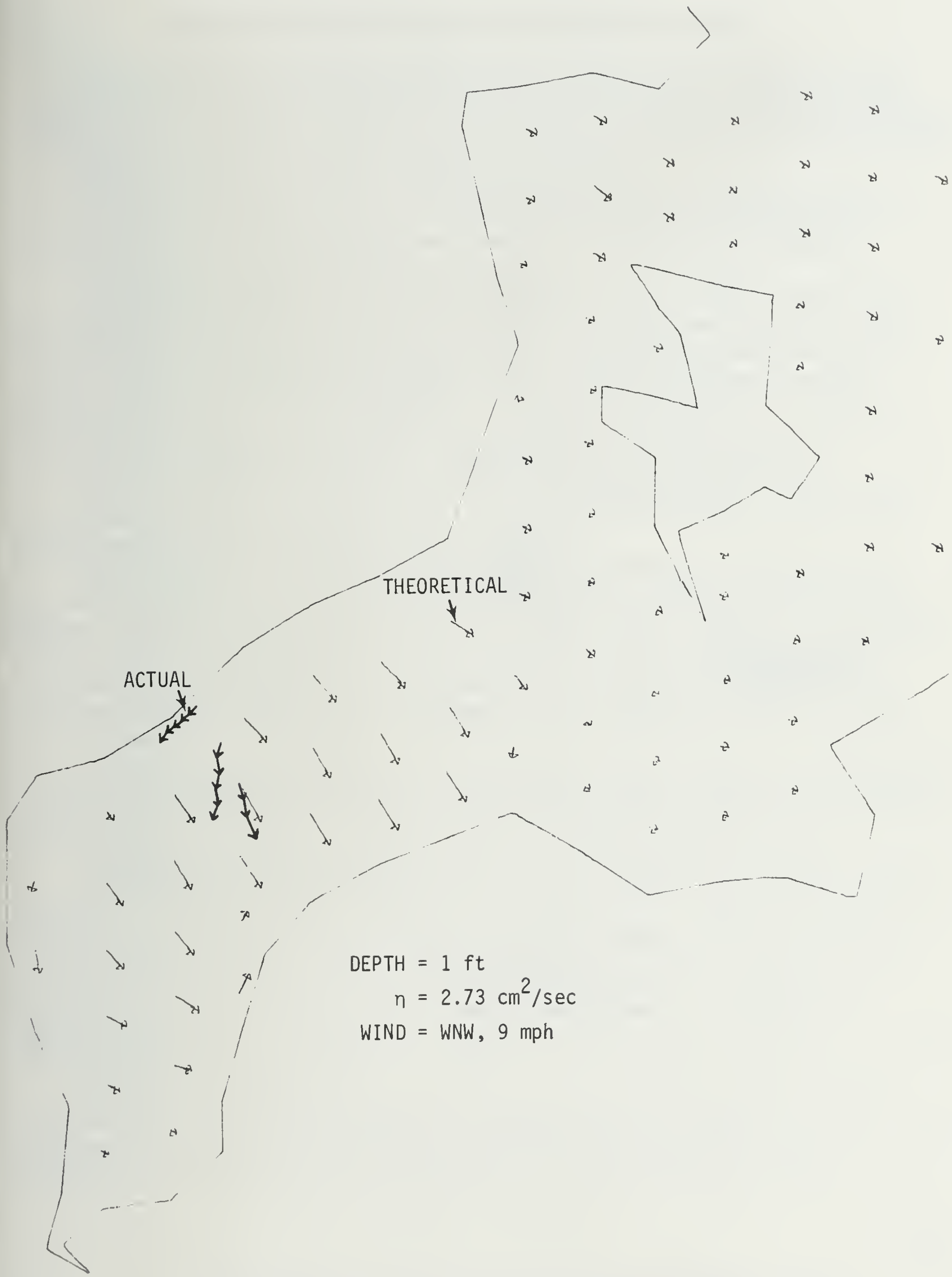


Figure 69. Theoretical and actual circulation patterns in Pistakee Bay, May 15, 1975

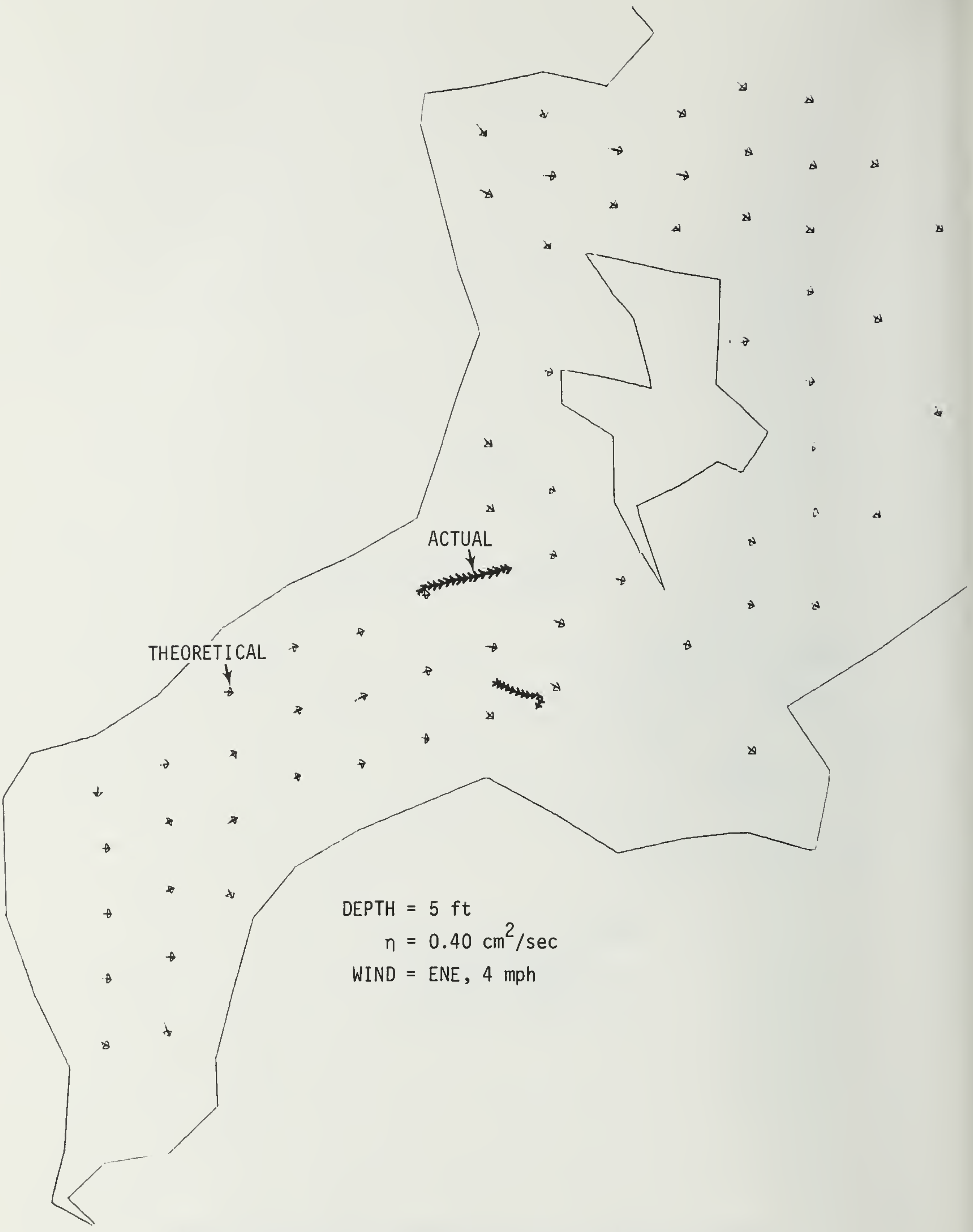


Figure 70. Theoretical and actual circulation patterns in Pistakee Bay, May 16, 1975

SUMMARY OF HYDRAULICS-HYDROLOGY OF LAKES

The hydraulics and hydrology of the Fox Chain of Lakes were developed from previously available data and from extensive new field data. The analyses provided water budgets including inflows and outflows, scour and deposition patterns, theoretical detention times in the various lakes, and circulation patterns in and between the lakes.

Depth-area and depth-storage relationships were developed for each of the lakes. The total storage of the lakes below a mean water surface elevation of 736.5 feet above msl is 38,718 acre-feet and the total surface area is 6844 acres. Pistakee Lake has the largest total surface area and storage capacity among the lakes.

Lake bed elevations in 1975 were determined from 26 cross sections. Comparisons with maps prepared about 20 years earlier showed that in general Grass, Bluff, Petite, Nippersink, and Pistakee Lakes had very little variation over that period. Lake Marie lost some capacity and in one cross section had deposition of 5 to 6 feet. The maximum observed deposition was about 8 feet in Channel Lake. Some erosion and deposition were observed in Lake Catherine. The southwestern part of Fox Lake showed deposition as much as 6 feet, though the northern part of that lake showed neither erosion nor deposition.

Most of the inflow to the lakes is from the Fox River and Nippersink Creek. Minor inflows come from Sequoit and Squaw Creeks and from Lily Lake Drain. A water budget analysis considering all inflows and outflows was made.

Measurements of interflow between the lakes indicated that when inflow rates are high, water generally moves in a southwesterly (downstream) direction toward the Fox River. However, when inflow rates are very low, the water within the lakes wanders about depending on wind velocity and direction before it finally moves downstream through the Fox River. As an example of apparent upstream movement, most of the time water moves from Grass Lake into Lake Marie, and on at least four occasions water was flowing into Channel Lake from Lake Marie.

Theoretical hydraulic detention times were computed for the lakes and combinations of lakes under various assumed conditions of lake capacity and flow. For one set of conditions, detention times varied from 5 days in April to about 21 days in September. During low flows, a considerable amount of time is needed to pass the flow through all of the lakes.

Extensive circulation data were collected at seven locations on four different occasions during 1975. In areas of negligible inflows, the circulation patterns in all of the lakes were governed by the wind. Even in areas of significant inflow, the wind dominated the movement of water as soon as diffusion of the inflow jets reduced the flow velocity. Generally, the surface water moves with the wind, and there is some return flow below certain depths. Measured wind-generated current profiles in the lakes indicated they generally follow a logarithmic distribution. The wind factor defined as the ratio of surface water velocity to wind velocity varied from 2 to 7 percent.

Theoretical circulation patterns in Pistakee Bay for a few selected wind conditions were computed by a finite element method. Calcomp plots were developed and the theoretical circulation patterns were compared with the measured circulation patterns. Correlation between the theoretical and measured circulation patterns was found to be good.

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Part 3. Water Quality Problems and Solutions

WATER QUALITY OF THE LAKES AND STREAMS

In order to assess the water quality characteristics, and to estimate the nutrient loads transported by the Fox River and other tributaries to the Fox Chain of Lakes, weekly water samples were obtained at six locations beginning December 4, 1974, and ending on November 26, 1975. Water samples collected from the Fox River at the Illinois Route 173 site, represent the water quality characteristics of the river entering the lake system, and the samples collected at Johnsburg represent the quality of water leaving the lake system. In addition, samples were collected from four other tributaries to the lakes, namely Nippersink Creek, Lily Lake Drain, Squaw Creek, and Sequoit Creek. The tributary sampling sites are shown in figure 71.

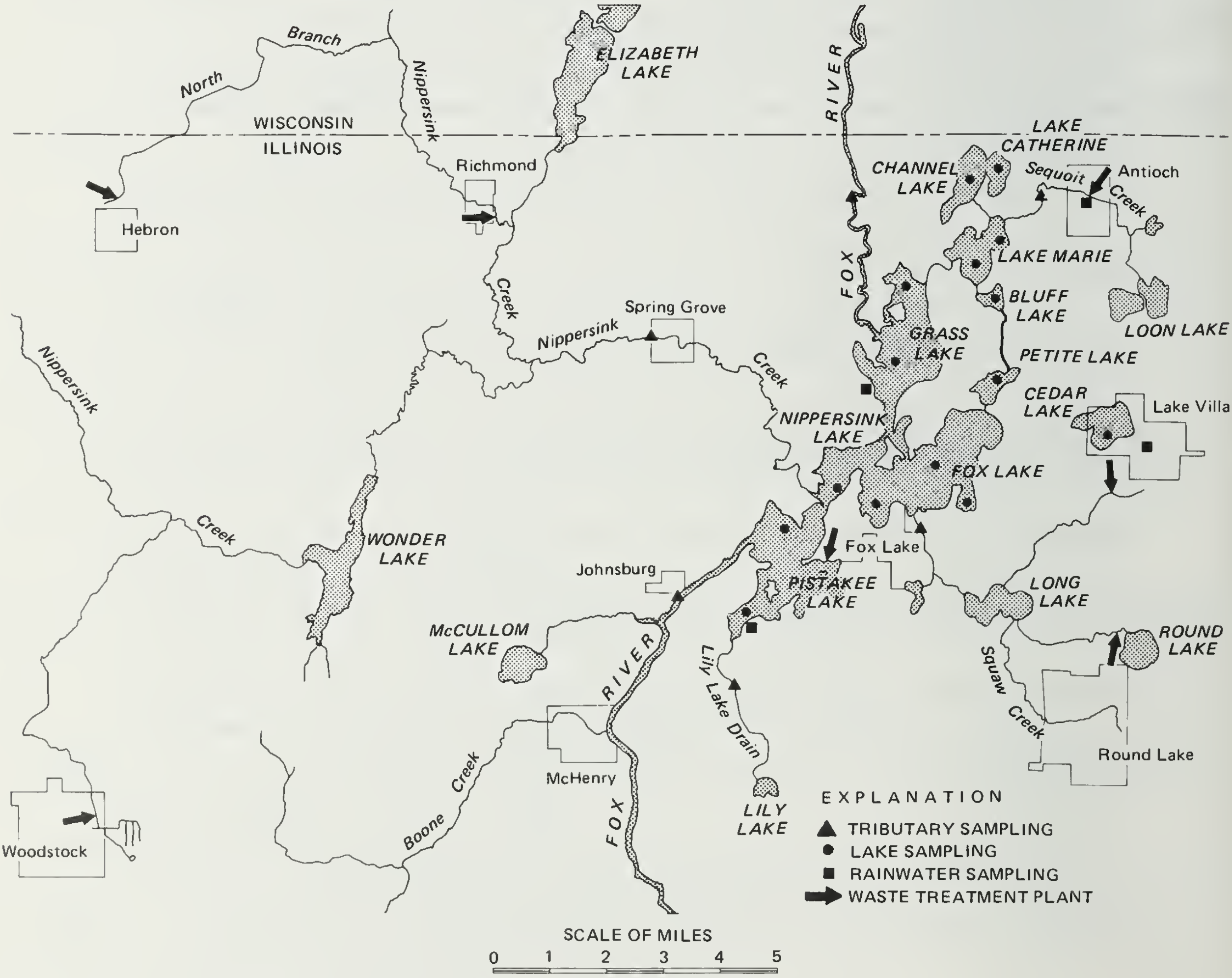

Figure 71. Water quality sampling locations in Fox Chain of Lakes

Water samples were collected in plastic lined bottles and transported to the laboratory through United Parcel Service. Upon receipt, they were kept refrigerated until all of the chemical analyses were completed. Observations were made for temperature and dissolved oxygen concentrations at the time of sample collection.

The daily flow values for the Fox River at Wilmot (about 2 miles upstream of the Illinois Route 173 sampling site) and for Nippersink Creek were obtained from U.S. Geological Survey (USGS) water resources data. Temporary wire-weight gages were installed on Sequoit Creek, Squaw Creek, and Lily Lake Drain. Daily stage observations were recorded for these creeks and daily average flows were estimated from stage-discharge relationships developed by the USGS for these streams. The average daily flow values for the Fox River at Johnsburg were estimated from the flow data developed for the Fox River at McHenry Dam by the Illinois Department of Transportation. The flow at Johnsburg was reduced in proportion to the watershed areas of the Fox River at Johnsburg and McHenry. Table 17 shows the watershed areas of the Fox River and other tributaries relevant to this investigation.

Table 17. Watershed Areas of Fox River and Other Tributaries

Location	*Watershed area (square miles)*
Fox River at Wilmot	868
Fox River at Johnsburg	1,184
Fox River at McHenry	1,253
Lily Lake Drain at Lincoln Road	4.75
Nippersink Creek at Spring Grove	193
Sequoit Creek at Highview Drive	10.74
Squaw Creek at Rollins Road	42.56

Chemical analyses on water samples were performed to determine turbidity, pH, alkalinity, hardness, nitrate–N, Kjeldahl–N, ammonia–N, total silica, total iron, chloride, sulfate, total solids, total dissolved solids, suspended solids, total phosphorus, dissolved orthophosphorus, and algal growth potential. The analyses were made according to the procedures outlined in table 18. Results of determinations are expressed as milligrams per liter (mg/l) except in the case of temperature, turbidity, and pH. Temperature is expressed in Celsius units, turbidity in Formazin turbidity units, and pH is dimensionless.

Algal growth potential is a laboratory procedure to evaluate the ability of filtered water samples to sustain algal growth, under standardized laboratory conditions, following inoculation with mixed algal culture (Wang et al., 1973). It is defined as the algal or organic mass resulting from a 7-day incubation of an algal culture grown on a natural substrate under standardized light and mixing conditions and expressed as milligrams of dry organic mass per liter of sample.

Temperature

Temperature plays a vital role in the rate of chemical reactions and the nature of biological activities in fresh water. Temperature affects the environment of the aquatic medium, e.g., viscosity, reaeration rates, and oxygen capacity. Composition of aquatic communities depends on temperature in addition to other characteristics of their environment.

Table 18. Analytical Procedures

Turbidity	Nephelometric method, using Turner Fluorometer Meter, Model 110. Formazin was used as a standard.
pH	Glass electrode method using Leeds and Northrup 7401 and later Beckman 4500
Alkalinity	Potentiometric method
Hardness	EDTA titrimetric method
Nitrate-N	Chromatropic method (West, 1966)
Kjeldahl-N	Kjeldahl digestion and ammonium determined by phenate method
Ammonium-N	Phenate method
Total silica	Molybdosilicate method
Total iron	Phenonthroline method
Chloride	Argentometric method
Sulfate	Turbidimetric method
Total dissolved solids	Residue on evaporation and filtration at 103 to 105°C
Total phosphorus	Sample was digested with sulfuric-nitric acids mixture and determined by ascorbic acid method
Dissolved orthophosphorus	Ascorbic acid method after filtration through 0.45μ filter paper
Algal growth potential	Method outlined by Wang et al. (1973)

Note: Unless otherwise stated all the methods used were according to Standard Methods (American Public Health Association, 1971)

Organisms have upper and lower thermal tolerance limits, optimum temperature for growth, and temperature limitations for migration and spawning. The Illinois Pollution Control Board (IPCB) stipulated that water temperatures in general should not exceed 15.5°C in the months of December through March and 32.2°C in the months of April through November (Illinois Pollution Control Board, 1972).

The means and ranges of values of temperature and other water quality parameters observed over a period of a year for the Fox River at Illinois Route 173, Lily Lake Drain, Nippersink Creek, Sequoit Creek, Squaw Creek, and the Fox River at Johnsburg are shown in tables 19 through 24. To facilitate comparison of the water quality characteristics for the tributaries to the Fox Chain of Lakes, the mean values are tabulated in table 25.

The observed temperatures in the streams ranged from 0°C in winter to 27.5°C in summer. Because there are no industrial thermal discharges to any of the tributaries, the variations in water temperature are solely due to natural causes. The IPCB regulations with respect to temperature were met by all the streams considered here.

Dissolved Oxygen

The dissolved oxygen (DO) content in water at equilibrium with a normal atmosphere is a function of the temperature and salinity of the water. The ability of water to hold oxygen decreases with increases in temperature or dissolved solids. Natural waters are not generally at equilibrium or at saturation point because temperatures are changing and the physical, chemical, and biological activities are utilizing or liberating oxygen. Inadequate DO in surface waters may contribute to an unfavorable environment for fish and other aquatic life. The absence of DO may give rise to odoriferous products of anaerobic decomposition. The Illinois Pollution Control Board (1972) mandates that the DO in the state's waters shall not be less than 6.0 mg/l during at least 16 hours of any 24-hour period, nor less than 5.0 mg/l at any time.

Table 19. Water Quality Characteristics, Fox River at Route 173

(Concentrations in mg/l)

Parameters	*Number of analyses*	*Mean*	*Range*
Temperature (°C)	51	13.8	0.0-27.0
Dissolved oxygen	49	10.9	5.0-15.0
Turbidity (FTU)	50	10.7	2.6-22.0
pH	52		7.75-8.59
Alkalinity	52	223	120-286
Hardness	53	305	136-386
Nitrate-N	52	1.17	0.07-4.51
Kjeldahl-N	52	1.27	0.21-4.08
Ammonia-N	52	0.22	0.00-0.88
Total silica	52	5.46	0.00-10.97
Total iron	52	0.92	0.08-4.35
Chloride	53	38	21-55
Sulfate	53	56	38-89
Total solids	52	447	294-527
Total dissolved solids	53	408	242-502
Suspended solids	52	38	0-126
Algal growth potential	53	56	1-142
Total phosphorus	53	0.24	0.11-0.79
Dissolved ortho-phosphorus	53	0.11	0.00-0.30

Table 20. Water Quality Characteristics, Lily Lake Drain

(Concentrations in mg/l)

Parameters	*Number of analyses*	*Mean*	*Range*
Temperature (°C)	52	12.8	0.0-26.0
Dissolved oxygen	51	8.9	2.0-15.0
Turbidity (FTU)	50	8.4	2.3-20.0
pH	53		7.93-8.62
Alkalinity	53	257	160-311
Hardness	53	336	136-447
Nitrate-N	52	0.63	0.06-2.70
Kjeldahl-N	52	1.29	0.19-2.64
Ammonia-N	52	0.43	0.03-13.00
Total silica	51	6.67	0.00-12.36
Total iron	52	0.78	0.18-5.96
Chloride	53	12	0-38
Sulfate	53	61	39-97
Total solids	52	443	354-584
Total dissolved solids	53	414	292-510
Suspended solids	52	29	0-182
Algal growth potential	53	25	5-141
Total phosphorus	53	0.10	0.0-0.63
Dissolved ortho-phosphorus	53	0.05	0.0-0.51

Table 21. Water Quality Characteristics, Nippersink Creek

(Concentrations in mg/l)

Parameters	*Number of analyses*	*Mean*	*Range*
Temperature (°C)	52	12.9	0.0-26.0
Dissolved oxygen	49	10.1	5.0-15.0
Turbidity (FTU)	50	11.1	2.3-54.0
pH	52		7.89-8.70
Alkalinity	52	234	142-329
Hardness	53	313	136-457
Nitrate-N	52	1.54	0.16-2.91
Kjeldahl-N	52	1.14	0.31-3.59
Ammonia-N	52	0.29	0.02-2.46
Total silica	52	7.04	0.0-13.20
Total iron	51	1.61	0.22-23.33
Chloride	53	30	17-62
Sulfate	53	59	36-87
Total solids	51	451	342-626
Total dissolved solids	53	409	270-480
Suspended solids	51	43	0-246
Algal growth potential	53	60	11-117
Total phosphorus	53	0.25	0.0-1.78
Dissolved ortho-phosphorus	53	0.16	0.0-1.51

Table 22. Water Quality Characteristics, Sequoit Creek

(Concentrations in mg/l)

Parameters	*Number of analyses*	*Mean*	*Range*
Temperature (°C)	51	12.5	0.0-25.0
Dissolved oxygen	50	8.2	3.0-15.0
Turbidity (FTU)	49	15.9	4.2-196.0
pH	53		7.82-8.47
Alkalinity	53	210	138-349
Hardness	53	261	115-386
Nitrate-N	52	1.03	0.32-4.68
Kjeldahl-N	51	3.46	0.42-16.70
Ammonia-N	52	2.16	0.05-11.10
Total silica	51	9.53	0.00-20.90
Total iron	51	1.64	0.07-27.08
Chloride	53	60	33-126
Sulfate	53	71	34-148
Total solids	51	488	308-1092
Total dissolved solids	52	442	290-678
Suspended solids	51	49	0-770
Algal growth potential	53	101	42-211
Total phosphorus	52	1.27	0.25-3.06
Dissolved ortho-phosphorus	51	1.09	0.0-2.76

The DO concentrations observed in the Fox River upstream of the Fox Chain of Lakes was never less than 5.0 mg/l. The DO concentration in the Fox River at Johnsburg was found to be less than 5.0 mg/l only 4 percent of the time. Lily Lake Drain, which drains a relatively small area of 4.75 square miles of marshland, showed the lowest oxygen concentration recorded. The lowest observed DO concentration in Sequoit and Squaw

Table 23. Water Quality Characteristics,
Squaw Creek

(Concentrations in mg/l)

Parameters	*Number of analyses*	*Mean*	*Range*
Temperature (°C)	51	13.5	0.0-27.5
Dissolved oxygen	50	10.1	3.0-16.0
Turbidity (FTU)	50	10.4	3.4-31.0
pH	53		7.98-8.75
Alkalinity	53	201	133-262
Hardness	53	289	102-413
Nitrate-N	52	0.92	0.04-2.37
Kjeldahl-N	52	2.49	0.5-9.89
Ammonia-N	52	1.11	0.03-3.65
Total silica	52	3.77	0.0-9.09
Total iron	52	0.66	0.09-4.28
Chloride	53	36	27-46
Sulfate	53	81	28-114
Total solids	52	449	392-510
Total dissolved solids	53	423	348-490
Suspended solids	52	27	0.0-72.0
Algal growth potential	53	78	10-170
Total phosphorus	53	0.83	0.21-1.94
Dissolved ortho-phosphorus	53	0.67	0.0-1.46

Table 24. Water Quality Characteristics,
Fox River at Johnsburg

(Concentrations in mg/l)

Parameters	*Number of analyses*	*Mean*	*Range*
Temperature (°C)	51	13.0	0.0-27.5
Dissolved oxygen	50	11.7	4.0-20.0
Turbidity (FTU)	50	12.9	2.4-28.0
pH	53		7.98-8.72
Alkalinity	53	211	138-302
Hardness	53	286	88-393
Nitrate-N	52	0.86	0.02-2.39
Kjeldahl-N	52	1.54	0.11-3.44
Ammonia-N	52	0.29	0.01-2.50
Total silica	52	3.91	0.0-9.83
Total iron	52	0.79	0.08-5.16
Chloride	53	35	20-63
Sulfate	53	54	37-72
Total solids	52	418	302-493
Total dissolved solids	53	386	266-460
Suspended solids	52	33	0-88
Algal growth potential	53	48	2-120
Total phosphorus	53	0.27	0.07-1.77
Dissolved ortho-phosphorus	53	0.13	0.0-1.47

Table 25. Comparison of Mean Values of Water Quality Characteristics
of Tributaries to the Fox Chain of Lakes

(Concentrations in mg/l)

Parameters	*Fox River at Route 173*	*Lily Lake Drain*	*Nippersink Creek*	*Sequoit Creek*	*Squaw Creek*	*Fox River at Johnsburg*
Temperature (°C)	13.8	12.8	12.9	12.5	13.5	13.0
Dissolved oxygen	10.9	8.9	10.1	8.2	10.1	11.7
Turbidity (FTU)	10.7	8.4	11.1	15.9	10.4	12.9
pH	7.75-8.59	7.93-8.62	7.89-8.70	7.82-8.47	7.98-8.75	7.98-8.72
Alkalinity	223	257	234	210	201	211
Hardness	305	336	313	261	289	286
Nitrate-N	1.17	0.63	1.54	1.03	0.92	0.86
Kjeldahl-N	1.27	1.29	1.14	3.46	2.49	1.54
Ammonia-N	0.22	0.43	0.29	2.16	1.11	0.29
Total silica	5.46	6.67	7.04	9.53	3.77	3.91
Total iron	0.92	0.78	1.61	1.64	0.66	0.79
Chloride	38	12	30	60	36	35
Sulfate	56	61	59	71	81	54
Total solids	447	443	451	488	449	418
Total dissolved solids	408	414	409	442	423	386
Suspended solids	38	29	43	49	27	33
Algal growth potential	56	25	60	101	78	48
Total phosphorus	0.24	0.10	0.25	1.27	0.83	0.27
Dissolved orthophosphorus	0.11	0.05	0.16	1.09	0.67	0.13

Creeks was 3.0 mg/l. The sampling stations on these two creeks were in close proximity to municipal waste treatment plants.

With the exception of the Fox River upstream of the lakes and Nippersink Creek, observed DO concentrations were on several occasions less than 5 mg/l. In Sequoit Creek and Lily Lake Drain, 10 percent of the observations were less than 5 mg/l. The average DO concentrations were high in all of the streams and each of them exhibited a high degree of supersaturation.

Turbidity

Turbidity in water is a measure of its ability to scatter and absorb light. Light scattering property of a liquid medium is dependent upon its suspended solids content as well as the particle size and shape. Wang and Brabec (1969) observed a high degree of correlation between turbidity and suspended solids concentration in the Illinois River. Silt and clay, derived from soil erosion, constitute the major components of turbidity causing particulate matter in streams.

Soil erosion and the concommitant sedimentation are dependent on factors such as intensity and duration of rainfall, soil characteristics, slope of the drainage basin, cropping practices, etc. Not only does erosion result in a loss of valuable top soil from agricultural lands, it also has deleterious effects on water quality, recreational enjoyment, fish propagation, and the management of impoundments.

The mean turbidity values measured in the tributaries to the Fox Chain of Lakes ranged from 8.4 to 15.9 FTU which are much less than the values determined by the Water Survey for the Spoon River in central Illinois. Turbidity in the Spoon River, measured at 5 different sites over a period of 2 years, ranged from 147 to 3470 FTU. The Spoon River is unimpounded along its entire length, whereas in the Fox River, Squaw Creek, and Nippersink Creek impoundments exist upstream of the sampling sites. Lily Lake Drain's small watershed is an undisturbed area and Sequoit Creek drains a small but mostly urban area.

pH, Alkalinity, and Hardness

The logarithm (base 10) of the reciprocal of the hydrogen ion concentration is commonly designated by the symbol pH. The concentration of weakly disassociated acids and bases markedly affects the pH value and the ease with which it can be altered. The presence of carbonates, phosphates, and similar ions give water a buffering capacity. Because pH values are reciprocals of logarithm of hydrogen ion concentrations, arithmetic means of pH values were not computed and only the ranges of values observed are shown in tables 19 through 25. The pH values for all the streams ranged between 7.75 and 8.75 which are within the range stipulated by IPCB.

The alkalinity of a water is its capacity to accept protons and is generally imparted by the bicarbonate, carbonate, and hydroxide components. The species composition of alkalinity is a function of pH and mineral composition. The carbonate equilibria, in which carbonate and bicarbonate ions and carbonic acid are in equilibrium, are the predominant chemical system present in natural waters. The IPCB does not stipulate any standard for alkalinity in natural waters. High alkalinity waters have been reported to have a distinctly unpleasant taste because they are generally associated with high values of pH, hardness, and dissolved solids (McKee and Wolf, 1963).

Any substance in water that will form an insoluble precipitate with soap causes hardness. Hardness is defined as the sum of the polyvalent cations expressed as the equivalent quantity of calcium carbonate. As iron, manganese, copper, barium, lead, zinc, and other trace elements are seldom present in appreciable concentrations in natural waters, hardness is attributable principally to calcium and magnesium.

Hard waters have no demonstrable harmful effects upon the health of consumers. The detrimental effects of hardness include excessive soap consumption, formation of scums and cruds in homes and laundries, and the formation of scales in boilers, hot water heaters, pipes, and utensils. The major detrimental effect of hardness is economic.

The alkalinity and hardness values observed in the Fox River and other tributaries are typical of surface waters in the Midwest. The mean alkalinity values observed in these streams varied from 201 to 257 mg/l which compare well with the mean values of 222 to 265 mg/l for the Spoon River at 5 locations. Hardness values ranged from 261 to 336 mg/l in the Fox River and other tributaries, whereas mean hardness values varied from 332 to 346 mg/l at 5 of the Spoon River sampling sites.

Nitrogen

Nitrogen in natural waters is generally found in the form of nitrate, organic nitrogen, and ammonia nitrogen. Nitrates are the end product of the aerobic stabilization of organic nitrogen, and as such they occur in polluted waters that have undergone self purification or aerobic treatment processes. Nitrates also occur in percolating groundwaters as a result of the application of fertilizer at surface sources. In surface waters and groundwaters, ammonia nitrogen results from the decomposition of nitrogenous organic matter, being a constituent of the complex nitrogen cycle. Ammonia nitrogen could also result from municipal and industrial waste discharges to streams and rivers.

The concerns for nitrogen as a contaminant in water bodies are twofold. First, because of adverse physiological effects on infants and because the traditional water treatment processes have no effect on the removal of nitrate, concentrations of nitrate plus nitrite as nitrogen are limited to 10 mg/l in public water supplies. Second, a concentration in excess of 0.3 mg/l is considered sufficient to stimulate nuisance algal blooms (Sawyer, 1974). The IPCB stipulates that ammonia nitrogen and nitrate plus nitrite as nitrogen should not exceed 1.5 and 10.0 mg/l, respectively.

The range of values of nitrate observed in the Fox River was 0.02 to 4.51 mg/l. In the streams, the overall range was 0.02 to 4.68 mg/l. The range of nitrate concentrations in other streams in Illinois was more extensive: 0.0 to 11.8 mg/l in the Spoon River, 0.05 to 16.08 mg/l in Six Mile Creek near Bloomington, and 3.70 to 10.17 mg/l in the Middle Fork Vermilion River. The observed magnitudes of nitrate were also 5 to 10 orders of magnitude smaller than those observed for central Illinois streams. The ammonia concentrations in Sequoit and Squaw Creeks were much higher than in the other streams in the area. This is mainly because of the closeness of municipal waste treatment discharges to the water sampling sites in these two creeks. The IPCB ammonia standard was found to be violated about 40 percent of the time in these two creeks.

The nitrate and ammonia loads transported by the Fox River and other streams are shown in table 26. The nitrogen load transported in terms of pounds per day was estimated by:

$$\text{Pounds per day} = \text{flow (cfs)} \times \text{concentration (mg/l)} \times 5.39$$

The means of average daily flows for a 7-day period were used in estimating the load. In the case of Lily Lake Drain, Sequoit Creek, and Squaw Creek, the overall means of flow observations were used on days when flow values could not be estimated for lack of stage

Table 26. Nitrate and Ammonia-N Transport by Different Streams

	Nitrate			Ammonia-N		
Streams	*lbs/day*	*lbs/sq mi/day*	*lbs/ac/yr*	*lbs/day*	*lbs/sq mi/day*	*lbs/ac/yr*
Fox River at Route 173	5354	6.17	3.50	1010	1.16	0.66
Lily Lake Drain	14	2.95	1.68	3	0.66	0.38
Nippersink Creek	1371	7.10	4.05	286	1.48	0.84
Sequoit Creek	52	4.87	2.78	54	5.06	2.89
Squaw Creek	168	3.95	2.25	211	4.96	2.83
Fox River at Johnsburg	4738	3.93	2.24	1391	1.15	0.66

observations. The stage observations for Sequoit Creek were not as regular as those for Lily Lake Drain or Squaw Creek. When a number of stage observations were missing in Sequoit Creek, the flows were estimated from Lily Lake Drain flows adjusted for drainage area and wastewater discharge from Antioch waste treatment plant. Information on pounds per square mile per day (lbs/sq mi/day) and pounds per acre per year (lbs/ac/yr) is also shown in table 26.

The mean nitrate concentration was highest in the Fox River. Presumably this is due to the fertilizer applied to agricultural lands and the self purification of municipal waste discharges in the upper reaches of the Fox River in Wisconsin. The nitrate load transported by the Fox River into the Chain of Lakes is about 5350 lbs/day. About 1370 lbs/day is transported by Nippersink Creek.

Sequoit and Squaw Creeks, as shown in table 25, have high mean concentrations of ammonia due mainly to the closeness of the stream sampling sites to waste treatment plants. The mean ammonia concentration in Lily Lake Drain, which drains mostly marshlands, is 0.43 mg/l. This is higher than the mean ammonia concentrations observed in Nippersink Creek and Fox River. However, mean nitrate concentrations in the latter two streams were significantly higher.

For purposes of comparison of nutrient transports by the different streams, unit load factors were considered. Nippersink Creek showed the highest rate of nitrate transported (4.05 lbs/ac/yr). This was followed by 3.50 lbs/ac/yr for Fox River at the Route 173 site. Unit ammonia-N loads transported by Sequoit and Squaw Creeks were several orders of magnitude higher than for the other streams.

The unit nitrate loads transported by all these streams are considerably less than the average nitrate contribution of 21 lbs/ac/yr observed on the 1030-square-mile drainage area for the Kaskaskia River upstream of Shelbyville (Harmeson and Larson, 1970).

Silica

The element silicon is not found free in nature. It occurs as silica or silicates, and is present in natural waters in soluble and colloidal forms. A silica cycle occurs in many bodies of water containing organisms such as diatoms that utilize silica in their skeletal structure. The silica removed from the waters may be slowly returned by re-solution of the dead organisms.

In concentrations found in natural or treated waters, silica does not appear to cause any adverse physiological effects. However, silica in high concentrations may cause difficulties arising from turbidity. Silica in boiler feed waters results in scaling.

Concentrations of silica in the Fox River and other tributaries do not appear to be excessive and are within the range cited in the literature (American Public Health Association, 1971). The mean and range of values observed for Sequoit Creek appear to have been influenced to a great extent by the Antioch waste treatment plant. Evans (1968), considering the addition of common ions from domestic use of water, documented that there is nearly a two- to three-fold increase in silica concentration in municipal wastewaters compared to the tap waters in their respective locations.

Total Iron

Iron ranks next to aluminum in abundance of metals in the earth's mantle. In spite of this, natural waters contain variable but minor amounts of iron. Under reducing conditions, iron exists in the ferrous state and is relatively soluble. In the absence of complex forming ions and upon exposure to oxygen, hydrated ferric oxide is formed which is insoluble. These precipitates tend to aggregate, flocculate, and settle or be adsorbed on surfaces. Hence the concentration of soluble iron in water with dissolved oxygen present is seldom high.

Generally accepted standards for iron in surface water supply sources is 0.3 mg/l or less. The limit is based on aesthetic and taste considerations rather than physiological reasons. The IPCB limits the concentration of total iron in streams to 1.0 mg/l.

The mean concentrations of total iron in Nippersink and Sequoit Creeks were found to be higher than the IPCB limits. All the other streams had mean total values less than the stipulated limits. On a few occasions, the concentration of iron observed in Nippersink and Sequoit Creeks exceeded 20 mg/l. In all the other creeks, the maximum observed was in the order of 5 mg/l. In Nippersink and Sequoit Creeks, observed iron concentrations exceeded the IPCB limit 41 and 31 percent of the time, respectively. In the other streams, the IPCB standard was violated about 19 to 30 percent of the time.

Chloride and Sulfate

Chlorides are found in practically all natural waters. They are conservative substances and have been used as a tracer element in engineering studies of surface waters and treatment unit processes. On the other hand, sulfate can occur as the final oxidized stage of sulfide, sulfites, and thiosulfites, and as the oxidized state of organic matter of the sulfur cycle. Sulfate can serve as a source of energy for sulfur bacteria. Both chlorides and sulfates in streams could be of mineral origin. They may emanate from municipal and industrial waste discharges as well.

Chloride and sulfate are the predominant anions causing what is known as 'permanent hardness.' Because of the salty taste caused by the chloride ion and the cathartic effect of sulfate, the IPCB limits each of these two constituents to 250 mg/l in public water supplies.

The mean chloride concentration of 12 mg/l in Lily Lake Drain was the lowest of all the observed mean values, reflecting the chloride contribution independent of cultural developments. The average concentration in Sequoit Creek, 60 mg/l, was the highest and was influenced by the effluent discharge from the Antioch waste treatment plant. All the other streams showed average values varying from 30 to 38 mg/l. The mean sulfate concentrations varied in these streams from 54 to 81 mg/l, as shown in table 25. The observed concentrations of chloride and sulfate in all the streams were well within the IPCB limits.

Total Solids, Total Dissolved Solids, and Suspended Solids

Total solids consist of dissolved solids and suspended solids. These could be further classified into the categories of inorganic and organic fractions, but only the two major forms of solids are dealt with here.

In natural waters, the total dissolved solids (TDS) consist mainly of bicarbonates, chlorides, sulfates, nitrates and phosphates of sodium, calicum, magnesium, and potassium with traces of iron, manganese, and other substances. The extent and composition of minerals occurring in natural waters is influenced by the geochemistry, morphometry, and land use patterns of the watershed contributing to the surface water and groundwater resources. The IPCB has stipulated a limit of 1000 mg/l for TDS in natural waters. High mineral content in water supplies render them unpalatable and such waters have a laxative action on new users.

Suspended solids consist normally of eroded silt, clay, organic detritus, and plankton. Man's activities alter and augment the suspended solids in surface waters by the discharge of liquid wastes from communities and industries, by increased erosion from cultivated areas and other results. A strong association between suspended solids and turbidity in natural waters has been reported (Wang and Brabec, 1969).

The mean values of total solids and total dissolved solids at all six sampling locations for stream quality characteristics are comparable. The temporal variations in these two parameters are moderate in all the streams except for one extremely high value observed in Sequoit Creek. The suspended solids concentrations exhibited a wider range of values, varying from 0 to about 250, with the exception of one unusually high value of 770 mg/l observed in Sequoit Creek.

Algal Growth Potential

Algal growth potential (AGP) is a bioassay procedure carried out under controlled laboratory conditions to evaluate the growth response of an algal inoculum in test waters. Traditionally, the primary productivity of a water body is predicted on the basis of the chemistry of the water such as alkalinity, dissolved solids, and particularly the concentrations of nutrients like nitrogen and phosphorus. The AGP procedure, developed by the Illinois State Water Survey (Wang et al., 1973), has been applied successfully to various surface water bodies in Illinois. It is a diagnostic tool, used to supplement the existing knowledge about the predictability of primary production in natural waters.

Evans and Schnepper (1974) reported that the mean AGP values observed for 14 streams in Illinois ranged from 14 to 77. The highest value had been observed for the Illinois River. The mean AGP values observed at the six sampling sites shown in table 25 indicate that Lily Lake Drain had the lowest value with 25 mg/l and Sequoit Creek the highest with 101 mg/l. Interestingly, the mean dissolved orthophosphorus, which is the readily available form of phosphorus, was the lowest at Lily Lake Drain and highest at Sequoit Creek. Inorganic nitrogen concentration, likewise, was the lowest and highest, respectively, at these two sites.

The range of values for AGP in all the streams, except Sequoit Creek, was considerable, varying from 1 to 170 mg/l. AGP values of less than 20 mg/l were generally associated with dissolved orthophosphorus values of 0.3 mg/l or less. All other values were equal to or greater than 0.14 mg/l, except for one observation of 0.0 mg/l of dissolved orthophosphorus in Sequoit Creek. The availability of unlimited quantities of inorganic nitrogen and phosphorus, due to the proximity of the Antioch municipal waste treatment plant discharges, resulted in high observed AGP values for Sequoit Creek.

It is difficult to relate the laboratory AGP values to naturally occurring algal growth conditions. Diurnal changes in factors such as turbidity, temperature, or sunlight could alter the growth potential in natural waters.

Phosphorus

Phosphorus as phosphate may occur in surface waters or groundwaters as a result of leaching from minerals or ores, in natural processes of degradation, or from agricultural drainage. Phosphorus is an essential nutrient for plant and animal growth and, like nitrogen, it passes through cycles of decomposition and photosynthesis.

Because phosphorus is essential to the plant growth processes, it has become the focus of attention in the entire eutrophication issue. With phosphorus being singled out as probably the most limiting nutrient and the one most easily controlled by removal techniques, various facets of phosphorus chemistry and biology have been extensively studied in natural environments. To prevent biological nuisances, IPCB (1972) stipulates, "Phosphorus as P shall not exceed 0.05 mg/l in any reservoir or lake, or in any stream at the point where it enters any reservoir or lake."

In any river system, the two aspects of interest for phosphorus dynamics are the phosphorus concentration and phosphorus flux (concentration times flow rate) as functions of time and distance. The concentration itself indicates the possible limitations that this nutrient can place on vegetative growth in the stream, and the phosphorus flux is a measure of phosphorus transport rate at any point in the river.

In the Illinois River, Wang and Evans (1970) found that the river flow rate was the principal variable that affected the soluble orthophosphorus concentration and that the relationship was an inverse one. A high flow rate was associated with a lower orthophosphorus concentration, i.e., a dilution effect. Unlike nitrate nitrogen, phosphorus applied as fertilizer is held tightly to the soil. Most of the phosphorus carried into streams and lakes from runoff over cropland will be in the particulate form. On the other hand, the major portion of phosphate-phosphorus emitted from municipal sewer systems is in a dissolved form. Consequently, the form of phosphorus, namely particulate or dissolved, is indicative of its source to a certain extent.

The means and range of values for total phosphorus and dissolved orthophosphorus for the Fox River and other tributaries are shown in tables 19 through 25. Sequoit Creek exhibited the highest mean, the widest range of values, and the highest of all the minimum values for total phosphorus and dissolved orthophosphorus. These high values were caused by the waste treatment plant at Antioch. The lowest phosphorus concentration was observed for Lily Lake Drain, which is the least affected by human cultural activities. The impact of different phosphorus concentrations in these streams on laboratory AGP values has been discussed earlier. The ratio of means of dissolved orthophosphorus to total phosphorus was the highest in Sequoit Creek at 0.86, followed by 0.81 for Squaw Creek. The ratio was the lowest for the Fox River at Illinois Route 173.

Table 27 shows the flux in pounds per day (lbs/day) and unit load factors expressed as pounds per square mile per day (lbs/sq mi/day) and pounds per acre per year (lbs/ac/yr) of total phosphorus and dissolved orthophosphorus at the six stream sampling sites. The unit load factor estimated for the Kaskaskia River at Shelbyville was 0.17 lbs/ac/yr (Engelbrecht and Morgan, 1959). The unit load factor for the Spoon River varied from 0.47 lbs/ac/yr near the headwaters to 0.26 lbs/ac/yr near its confluence with the Illinois River. It decreased

Table 27. Phosphorus Transport by Different Streams

Streams	Total phosphorus lbs/day	Total phosphorus lbs/sq mi/day	Total phosphorus lbs/ac/yr	Dissolved orthophosphorus lbs/day	Dissolved orthophosphorus lbs/sq mi/day	Dissolved orthophosphorus lbs/ac/yr
Fox River at Route 173	1187	1.37	0.78	428	0.49	0.28
Lily Lake Drain	1.7	0.36	0.20	0.45	0.95	0.05
Nippersink Creek	223	1.16	0.66	119	0.62	0.35
Sequoit Creek	61	5.68	3.24	33	3.07	1.75
Squaw Creek	131	3.08	1.76	107	2.51	1.43
Fox River at Johnsburg	1093	0.91	0.52	509	0.42	0.24

gradually in the downstream direction and thus exhibited the dilution effect. The phosphorus transport data for the Fox River and other tributaries to the Fox Chain of Lakes, with the exception of Lily Lake Drain, appear to be several orders of magnitude higher when compared with the Kaskaskia River or Spoon River data.

The phosphorus concentrations in the Fox River, Sequoit Creek, and Squaw Creek exceeded the IPCB limit all the time. Phosphorus concentrations were less than 0.05 mg/l for Nippersink Creek in only 3 out of the 53 observations over a period of 1 year. Phosphorus concentrations exceeded 0.05 mg/l for Lily Lake Drain in 32 of the 53 observations.

WASTEWATER TREATMENT FACILITIES AND EFFLUENT CHARACTERISTICS

The shoreline around the Fox Chain of Lakes has been intensely developed with permanent year-round homes, condominiums, hotels, restaurants, marinas, and service facilities ancillary to boating and other recreational activities. In addition, approximately 30 miles of dredged channels have been created to develop waterfront properties. It is estimated that 85 percent of the developed properties on the shores of the Chain are in unincorporated areas and remain on septic tank disposal systems. Detailed surveys conducted by the health departments of McHenry and Lake Counties indicate there are about 6900 residential units being served by household septic tank systems. In addition, some schools, churches, hotels, motels, and commercial enterprises are similarly served.

An estimated waste flow of 155,000 gallons per day (gpd) is applied to septic tank-tile field systems around the lakes and in the immediate vicinity (William Mellon and Richard A. Wissell, personal communication, 1976). Analyses of the effluent quality characteristics of the septic tank systems were not made. However, the impact of this method of waste disposal on the water quality of the lakes, with specific reference to the nutrients nitrogen and phosphorus, is discussed in the section *"Nutrient Budget."*

There are seven municipal waste treatment plants (WTP) located within the Chain's watershed that discharge directly or indirectly into the lake system. The WTPs are located at Hebron, Richmond, Woodstock Northside, Lake Villa, Round Lake Sanitary District, Antioch, and Fox Lake. Of these, only the Fox Lake WTP discharges directly to the lake system; all of the other treatment plants discharge to streams which are tributary to the lakes. Treated effluent from the Woodstock Die Casting Company and a Hebron meat packing industry are the only significant industrial discharges in the area. The relative locations of these waste treatment plants with respect to the Chain of Lakes along with the tributaries to the lakes are shown in figure 71. Information pertaining to the population presently served,

Table 28. Municipal Waste Treatment Plants Discharging Directly or Indirectly into the Chain of Lakes

Municipality served	*Receiving stream*	*Population 1975*	*Design flow (mgd)*	*Type of treatment**	*Estimated efficiency (%)***
Hebron	Nippersink	780	0.110	TF	80-85
Richmond	Nippersink	1,150	0.375	Biodisc	80-85
Woodstock (north-side	Nippersink	10,230	3.500	AS	85-90
Lake Villa	Eagle Creek-Squaw Creek	1,090	0.300	AS	85-90
Round Lake Sanitary District	Squaw Creek	16,350	1.600	TF, P	85-90
Antioch	Sequoit Creek	3,680	1.000	AS, P	85-90
Fox Lake	Myers Bay-Pistakee Lake	4,510	0.720	TF	80-85

*TF = trickling filter; AS = activated sludge; P = polishing ponds
**Estimated efficiency in 5-day BOD removal

design flow, type of treatment provided, and other details regarding the seven WTPs are provided in table 28. Details of plant improvements, modifications, future expansions, and the current effluent quality characteristics of each of these wastewater treatment facilities are reported individually here.

In order to assess the wastewater effluent characteristics, four separate visits were made to the plants to collect samples for chemical analyses. Grab samples were collected from treatment plants employing polishing ponds or oxidation lagoons. In all other cases composited samples were obtained. The samples, representative of plant flow weighted samples, were collected at 30-minute intervals during the period 9 a.m. to 3 p.m. The samples were stored in ice during collection and transportation and refrigerated until the necessary analyses were performed. Alkalinity, pH, nitrate-N, Kjeldahl-N, ammonia-N, chemical oxygen demand (COD), total solids, dissolved solids, total phosphorus, and dissolved orthophosphorus were determined. Methods of chemical analyses performed are reported in the section *"Water Quality of the Lakes and Streams."*

Hebron WTP

The municipal wastewater is treated in a 0.11 mgd Imhoff trickling filter plant. The treatment facility for the meat-packing industry consists of two anaerobic lagoons and two oxidation lagoons. The facility is designed to handle trade wastes from a meat-packing operation processing 200 head of cattle per day. The industrial waste treatment facility is owned and operated by the city of Hebron. Tables 29 and 30 show the chemical characteristics of the four samples obtained at these plants and also the means of the observed values. The trickling filter plant discharges higher concentrations of inorganic nitrogen and phosphorus than the lagoons. The ratios of dissolved orthophosphorus to total dissolved phosphorus are 0.83 and 0.63, respectively, for the trickling filter plant and the lagoons.

In the near future, waste flows from the municipal and industrial facilities are to be combined and treated by the contact stabilization activated sludge process. The final effluent, after chlorination, is to be disposed of by spray irrigation. The sludge generated at the treatment plant is also to be used in spray irrigation. This scheme has been approved by the Illinois Environmental Protection Agency.

Table 29. Hebron Trickling Filter Plant Effluent Characteristics

(Concentrations in mg/l)

Parameters	*Dates of observations*				
	12/12/74	*3/25/75*	*8/11/75*	*11/6/75*	*Mean*
pH	7.85	8.06	7.88	8.31	
Alkalinity	333	364	386	361	361
Nitrate-N	13.51	11.23	5.91	17.14	11.95
Kjeldahl-N	10.36	44.64	4.44	17.0	19.11
Ammonia-N	7.77	20.00	3.64	8.82	10.05
COD	52.23	86.08	72.44	71.18	70.48
Total solids	996	1165	1155	1262	1145
Dissolved solids	949	1105	1128	1192	1094
Total phosphorus	8.77	10.79	12.89	21.70	13.54
Dissolved orthophosphorus	8.49	9.62	11.32	12.58	10.50
Dissolved orthophosphorus/total dissolved phosphorus	0.97	0.89	0.88	0.58	0.83

Table 30. Hebron Lagoon Effluent Characteristics

(Concentrations in mg/l)

Parameters	*Dates of observations*				
	12/12/74	*3/25/75*	*8/11/75*	*11/6/75*	*Mean*
pH	8.38	7.59	9.53	8.75	
Alkalinity	400	413	164	274	313
Nitrate-N	1.60	1.37	0.47	0.66	1.03
Kjeldahl-N	20.81	17.68	13.80	25.00	19.32
Ammonia-N	16.27	10.70	0.06	0.62	6.91
COD	118.04	104.64	229.29	312.35	191.08
Total solids	1445	1057	1678	1894	1519
Dissolved solids	1320	1004	1366	1586	1319
Total phosphorus	3.59	6.31	2.44	2.96	3.83
Dissolved orthophosphorus	2.43	5.73	0.75	1.79	2.68
Dissolved orthophosphorus/total dissolved phosphorus	0.68	0.91	0.31	0.60	0.63

Table 31. Richmond WTP Effluent Characteristics

(Concentrations in mg/l)

Parameters	*Dates of observations*				
	12/12/74	*3/25/75*	*8/11/75*	*11/6/75*	*Mean*
pH	7.73	8.00	7.78	7.65	
Alkalinity	333	324	369	349	344
Nitrate-N	8.02	4.69	0.54	5.89	4.79
Kjeldahl-N	15.84	15.45	15.60	3.30	12.55
Ammonia-N	9.67	15.40	8.89	0.80	8.69
COD	59.17	43.88	59.21	47.06	52.33
Total solids	942	1079	793	1066	970
Dissolved solids	888	1044	788	1066	947
Total phosphorus	7.16	4.29	5.37	20.13	9.24
Dissolved orthophosphorus	5.62	3.51	3.55	9.59	5.57
Dissolved orthophosphorus/total dissolved phosphorus	0.78	0.82	0.66	0.48	0.69

With the proposed disposal system, nutrient emissions, particularly that of phosphorus, will be totally eliminated from Nippersink Creek.

Richmond WTP

The expansion and modification of this treatment plant with a design flow of 0.375 mgd was completed in 1975. Secondary treatment is carried out with 4-stage biodisc units following Imhoff tanks. The biodisc units are similar to trickling filters where a fixed biological mass is exposed alternately to the dissolved organic matter and air. The secondary solids are returned to the Imhoff tanks for anaerobic digestion. The treated effluent is chlorinated in an aerated chlorine contact chamber prior to discharge into Nippersink Creek. Digested solids are dried in sludge drying beds and disposed by landfill. Provision is made for adding alum between the third and fourth stages of the biodiscs for phosphorus precipitation and removal in the final clarifiers. Phosphorus reduction from the wastewater effluent is yet to be practiced. Table 31 shows the wastewater effluent characteristics for this plant.

Woodstock Northside WTP

This treatment plant is in the process of expansion and upgrading. Waste flow is given the conventional activated sludge treatment after grit and primary solids removal. Chemicals will be added for phosphorus removal prior to the secondary clarification stage. The waste flow will pass through two polishing ponds, then will be chlorinated and discharged. Solids generated in the treatment process will be aerobically digested and dried in sludge drying beds prior to ultimate disposal. At the time of sampling for wastewater effluent characterization, the phosphorus removal step was not practiced. Results of the chemical analyses of the effluent samples pertaining to this treatment plant are shown in table 32.

Woodstock Die Casting Company WTP

The company is primarily engaged in nonferrous die casting and plating operations. The municipal and industrial waste streams generated in the plant are collected separately with the municipal waste discharged to the city sewers. Different types of trade wastes are segregated initially and given pretreatment before being pumped to the central waste treatment plant. For example, chromium bearing rinse waters are treated by sulfonation, cyanide bearing waste waters are chlorinated to oxidize cyanide, and finally acid and alkaline rinse waters are diverted to a collection sump for neutralization, all prior to being pumped to the central collection tank at the treatment plant.

The collected waste streams are treated through a neutralizing tank using an automatic pH controlled feed system for the addition of lime or sulfuric acid. The neutralized water then flows through upflow clarifiers where alum and polyelectrolytes are added. The clarified waters are filtered through dual media filters before being discharged to the receiving stream. The sludge is initially thickened in a sludge thickener with the addition of polyelectrolytes. The sludge is then dewatered in a vacuum filter using diatomaceous earth as a filtering aid. The dewatered sludge is disposed of by landfill.

The company has plans to increase the number of upflow clarifiers by two, thus doubling the retention time in the clarifiers. The chemical characteristics of the final waste effluent from the treatment plant are shown in table 33.

Table 32. Woodstock Northside WTP Effluent Characteristics

(Concentrations in mg/l)

	Dates of observations				
Parameters	*12/12/74*	*3/25/75*	*8/11/75*	*11/5/75*	*Mean*
pH	7.57	7.85	7.72	8.18	
Alkalinity	404	337	369	353	366
Nitrate-N	0.31	0.65	0.12	1.12	0.55
Kjeldahl-N	13.22	7.67	11.65	35.9	17.11
Ammonia-N	12.25	5.97	10.04	23.94	13.05
COD	35.02	67.17	45.98	42.35	47.63
Total solids	1352	1134	1150	1556	1298
Dissolved solids	1308	1075	1136	1516	1259
Total phosphorus	7.29	4.94	7.95	10.06	7.56
Dissolved orthophosphorus	7.23	3.94	6.02	4.72	5.63
Dissolved orthophosphorus/total dissolved phosphorus	0.99	0.80	0.86	0.47	0.78

Table 33. Woodstock Diecasting Company Effluent Characteristics

(Concentrations in mg/l)

	Dates of observations			
Parameters	*4/28/75*	*8/11/75*	*11/5/75*	*Mean*
pH	9.69	9.42	9.10	
Alkalinity	231	324	298	284
Nitrate-N	1.93	1.12	2.04	1.70
Kjeldahl-N	2.43	2.61	1.05	2.03
Ammonia-N	0.13	0.38	0.07	0.19
COD	41.54	42.83	40.00	41.46
Total solids	558	1259	1236	1018
Dissolved solids	536	1258	1212	1002
Total phosphorus	3.35	3.23	1.87	2.82
Dissolved orthophosphorus	3.19	2.62	1.10	2.30
Dissolved orthophosphorus/total dissolved phosphorus	0.95	0.81	0.59	0.78

Table 34. Lake Villa WTP Effluent Characteristics

(Concentrations in mg/l)

	Dates of observations				
Parameters	*11/21/74*	*4/8/75*	*7/8/75*	*11/5/75*	*Mean*
pH	8.21	8.33	8.35	7.91	
Alkalinity	284	284	297	243	277
Nitrate-N	0.71	0.17	0.26	15.62	4.19
Kjeldahl-N	8.62	14.05	5.67	1.20	7.39
Ammonia-N	3.82	11.88	2.51	0.52	4.68
COD	43.01	72.93	35.81	24.12	43.97
Total solids	761	628	560	714	666
Dissolved solids	717	545	532	674	617
Total phosphorus	5.19	4.32	3.61	14.94	7.02
Dissolved orthophosphorus	4.44	2.98	3.02	7.08	4.38
Dissolved orthophosphorus/total dissolved phosphorus	0.86	0.69	0.84	0.47	0.72

Lake Villa WTP

Until the early part of 1975, the wastewater was treated in an Imhoff tank and two oxidation lagoons, one of which was aerated with diffused air. An entirely new waste treatment facility consisting of a packaged activated sludge treatment process with a design capacity of 0.3 mgd is now in operation. The effluent is chlorinated and discharged to Eagle Creek which empties into Long Lake. There is no provision for phosphorus removal in the new treatment facility.

The Northeastern Illinois Planning Commission (NIPC, 1974) has proposed a regional wastewater plan which recommends that the new plant be operated only until its bonded indebtedness has been satisfied. Anticipated excess flow could be diverted to the regional interceptor and ultimately the area could be served by a proposed regional plant. (Details of the proposed regional plan are discussed on page 114.) Wastewater effluent characteristics are shown in table 34.

Round Lake Sanitary District WTP

The present facility is a 1.6 mgd trickling filter plant with three lagoons. The first lagoon is aerated and the final effluent is chlorinated. The Sanitary District serves portions of the municipalities of Round Lake, Round Lake Beach, Round Lake Heights, and Round Lake Park.

In its 'interim expansion and upgrading' plans, the Sanitary District has proposed changes to the clariflocculator, anaerobic digesters, and aeration tanks; installation of tertiary filters; and modifications to the trickling filters, lagoons, and other facilities. The Sanitary District has also proposed the construction of four new interceptors in the communities it serves.

NIPC proposed that the area be integrated into the Lake County regional wastewater treatment system. The regional plan recommends the construction of the four new interceptors up to the Round Lake treatment plant. When full treatment at the plant is terminated, the plant would be kept on a standby basis to temporarily store and/or treat excess wet weather flows. The citizens of the Sanitary District area voted in 1973 against joining the County regional system by a 3 to 1 margin.

In the existing treatment facilities, phosphorus removal is not practiced. Table 35 shows the wastewater effluent chemical quality characteristics.

Antioch WTP

Until mid-1975, the wastewater at this plant was treated in an 0.5 mgd activated sludge plant with three tertiary ponds. The final effluent was chlorinated and discharged to Sequoit Creek. The treatment facilities have since been expanded and upgraded to a design capacity of 1.0 mgd. The wasteflow is given a tertiary treatment in mixed media filters for solids removal. The polishing ponds are bypassed prior to chlorination. Phosphorus removal facilities have been incorporated now, but were not commissioned at the time of sampling.

NIPC (1974) proposes that the plant be operated until its economic life expires. Following that, the plan calls for it to be used to either store and release excess flows for treatment at the regional plant or to treat the excess flows on site and discharge the effluent.

Effluent quality characteristics for this treatment plant are shown in table 36.

Table 35. Round Lake WTP Effluent Characteristics

(Concentrations in mg/l)

	Dates of observations				
Parameters	*11/21/74*	*4/8/75*	*7/8/75*	*11/6/75*	*Mean*
pH	7.85	8.22	7.98	8.28	
Alkalinity	306	293	311	278	297
Nitrate-N	0.68	0.52	0.25	0.80	0.56
Kjeldahl-N	27.17	34.12	11.30	25.30	24.47
Ammonia-N	16.62	23.45	5.23	15.30	15.15
COD	27.67	42.74	35.81	60.88	41.78
Total solids	683	629	600	696	652
Dissolved solids	668	604	578	658	627
Total phosphorus	9.02	4.63	3.89	2.83	5.09
Dissolved orthophosphorus	7.82	3.27	3.61	2.03	4.18
Dissolved orthophosphorus/total dissolved phosphorus	0.87	0.71	0.93	0.72	0.81

Table 36. Antioch WTP Effluent Characteristics

(Concentrations in mg/l)

	Dates of observations				
Parameters	*11/21/74*	*4/8/75*	*7/8/75*	*11/5/75*	*Mean*
pH	8.10	7.90	8.12	8.04	
Alkalinity	235	284	315	353	297
Nitrate-N	12.76	2.36	0.40		5.17
Kjeldahl-N	2.14	6.53	12.3	24.0	11.24
Ammonia-N	2.09	5.06	5.44	10.75	5.84
COD	18.94	29.85	51.29	46.76	36.71
Total solids	802	653	640	670	691
Dissolved solids	744	624	592	652	653
Total phosphorus	8.62	3.37	3.78	7.86	5.91
Dissolved orthophosphorus	7.16	3.26	3.44	3.62	4.37
Dissolved orthophosphorus/total dissolved phosphorus	0.83	0.97	0.91	0.46	0.79

Table 37. Fox Lake WTP Effluent Characteristics

(Concentrations in mg/l)

	Dates of observations				
Parameters	*11/21/74*	*4/8/75*	*7/8/75*	*11/5/75*	*Mean*
pH	8.15	8.38	8.08	8.21	
Alkalinity	413	319	395	443	393
Nitrate-N	1.43	0.47	3.00	1.51	1.60
Kjeldahl-N	21.93	19.14	15.8	24.0	20.22
Ammonia-N	18.62	19.12	6.77	11.79	14.08
COD	30.68	107.87	70.64	68.53	69.43
Total solids	1252	1035	1124	1244	1164
Dissolved solids	1236	953	1066	1202	1114
Total phosphorus	7.39	5.79	4.25	11.01	7.11
Dissolved orthophosphorus	6.95	3.29	3.72	5.35	4.83
Dissolved orthophosphorus/total dissolved phosphorus	0.94	0.57	0.88	0.49	0.72

Fox Lake WTP

The existing treatment designed for an average flow of 0.72 mgd, presently treats an annual average flow of 0.25 mgd. The waste flow is treated by trickling filters, chlorinated, and discharged. Lake County Department of Public Works and the village of Fox Lake have submitted a joint application for implementing the regional plan in this service area. Included is the construction of a new 6 mgd plant which is discussed below. The effluent quality characteristics for the Fox Lake WTP are shown in table 37.

Regional Plan — Lake County Northwest Service Area

The Northeastern Illinois Planning Commission believes the most critical water pollution problem in northeastern Illinois lies in the northwestern part of Lake County (NIPC, 1974). Here, in the Commission's judgment, exists deteriorating water quality in the Chain of Lakes, health hazards from malfunctioning septic tanks, and inadequate wastewater treatment plants.

The regional plan proposed by NIPC (1974) for the northwestern sector of Lake County calls for the construction of a single treatment plant located in the village of Fox Lake, together with a regional interceptor sewer system which will provide service to the major part of the sector. The proposed regional system will permit consolidation of Fox Lake, Round Lake Sanitary District, Antioch, and Lake Villa municipal treatment facilities. Sewer service will be available to existing developments now on septic tanks and to industrial and miscellaneous plants in the sector when and where it is found economical to make the necessary connections.

The plan envisages total waste flows of 6.0 mgd by 1980, 12.0 mgd by 1990, and 19.0 mgd by 2010. The initial construction cost would be $12.9 million. This includes construction of a 6.0 mgd waste treatment plant at Fox Lake together with the first phase of the interceptor system and related pumping stations. The plant design criteria include secondary treatment, phosphorus removal, nitrification-denitrification, and a polishing lagoon.

The existing Fox Lake plant is planned to be phased out of service with the implementation of the regional plan. The Round Lake, Antioch, and Lake Villa plants will continue in service until their economic lives expire. At that time they will be placed on standby service to handle excess wet weather flows. It is contemplated that waste treatment service could be provided to areas in the Nippersink Creek drainage basin in McHenry County at a later date upon completion of other interceptor sewers not included in the plan now.

Pollution and Abatement Plans for Fox River Watershed, Wisconsin

Because 868 square miles of the Fox River watershed (measured at Wilmot near the Wisconsin-Illinois border) lies within Wisconsin, the water quality of the Fox River as it enters the Fox Chain of Lakes has a significant impact on the water quality of the Chain of Lakes. Therefore, the magnitude of waste loads, relative importance of municipal, agricultural, and urban sources of pollutants, and the water quality management needs assessed by the Southeastern Wisconsin Regional Planning Commission (1969) are summarized here.

Twelve major municipal waste discharges exist within the Fox River watershed in Wisconsin. Information about population served, the type and efficiency of treatment used, approximate daily discharge and other pertinent information is given in table 38. Four of the

Table 38. Major Municipal Waste Discharges in Fox River Watershed within Wisconsin, 1966*

Municipality served	*Population served*	*Average daily discharge (mgd)*	*Type of treatment***	*Efficiency of BOD removal (%)*	*5-day BOD discharged (lbs/day)*
Sussex	1,400	0.19	TF	80	48
Brookfield	2,200	0.32	AS	78	82
Pewaukee	2,900	0.32	TF	80	99
Waukesha	37,500	7.50	TF	85	1,770
Mukwonago	1,900	0.19	TF	80	65
Waterford	1,600	0.19	P	25	204
East Troy	1,500	0.19	TF	80	51
Lake Geneva	4,500	0.52	TF	80	153
Burlington	6,200	1.10	TF	80	210
Twin Lakes	3,100	0.18	TF	80	105
Genoa City	1,050	0.10	TF	80	36
Silver Lake	200	0.02	EA	80	7

*Southeastern Wisconsin Regional Planning Commission
**TF = trickling filter; AS = activated sludge; P = primary; and EA = extended aeration

municipal plant discharges, including the Waukesha waste treatment plant with the maximum discharge, are located in the headwaters of the Fox River. Four other waste discharges, including the Burlington waste treatment plant, are distributed along the rest of the main stem of the Fox River. The other four, including that of Lake Geneva, are located on tributaries to the Fox River.

All of the municipal waste treatment plants in the watershed, except the one at Waterford, provide secondary treatment. Almost 75 percent of the total population load as measured by 5-day BOD enters the river at and above the city of Waukesha. Approximately 75 percent of the low flow of the Fox River below Waukesha consists of effluent from the waste treatment plants at Waukesha, Brookfield, Pewaukee, and Sussex.

Nineteen major industrial waste discharges exist within the Fox River watershed. Eight are located in the vicinity of the city of Waukesha. Manufacturing, milk processing, canning, and cooling are the major uses for these wastewaters. No information is available on the quantity or quality of the waste effluents discharged.

While discussing the types of pollutants (silt, nutrients, pesticides, organic wastes, etc.) arising from agricultural practices, and their possible impact on receiving streams and lakes, the Southeastern Wisconsin Regional Planning Commission (1969) concludes that agricultural drainage and runoff generally constitute a relatively minor source of stream pollution in the basin in comparison with the pollution caused by municipal discharges. This judgment is based on the stream quality data for the Fox River and its watershed. Likewise the Commission has concluded that the effects of urban runoff and combined sewer overflows on stream water quality in the Fox River watershed is insignificant compared with the waste sources from the municipal sewage treatment plants.

The Commission's recommended plan for pollution abatement in the Fox River watershed proposes the following measures:

1) Provide advanced waste treatment for biochemical oxygen demand and nutrient removal and disinfection at all major waste discharge locations within the watershed. This would include:
    - A single large sewage treatment plant providing advanced waste treatment for the four municipalities within the entire upper watershed, along with a system of trunk sewers to convey the wastes from the upper watershed to this plant

- Advanced waste treatment facilities at the six sewage treatment plants in the lower reaches of the watershed, i.e., Mukwonago, Waterford-Rochester, East Troy, Lake Geneva, Burlington, and Twin Lakes
- Silver Lake and Genoa City would continue to be served by secondary treatment plants with post chlorination disinfection

2) Institute improved soil and water conservation practices on farmlands in the agricultural areas of the basin in order to minimize the effects of runoff from agricultural areas containing silt, fertilizers, herbicides, and pesticides.
3) Connect to the public sanitary sewerage systems 16 of the 19 major industrial waste sources. In addition the plan recommends that all other industrial and resort waste discharges not connected to centralized public sanitary systems be given a level of treatment equivalent to secondary treatment and disinfection.

The Commission reported that implementation of the recommended stream and lake water quality management plan would abate all of the existing major sources of stream pollution within the watershed. It is anticipated that the municipal waste loadings on the stream system would be reduced from 2800 pounds per day of BOD and 390 pounds per day of phosphorus to 900 pounds and 30 pounds, a reduction of 68 and 92 percent, respectively.

LIMNOLOGY OF THE LAKES

In order to assess the physical, chemical, and biological characteristics of the lake system, field trips were undertaken to make *in situ* observations of temperature, dissolved oxygen, and secchi disc readings and to obtain water samples for chemical and biological evaluations. Biweekly trips were made during the period May 19, 1975, to July 14, 1975, and thereafter weekly trips were made until October 20, 1975.

Fourteen lake stations were established for water sampling and *in situ* observations (figure 72). These sampling sites were selected at the deepest part of each of the lakes. In waters with depths greater than 30 feet, as in the case of Lakes Catherine, Channel, Marie (west basin), and Pistakee Bay, water samples were obtained at three different depths – at the surface, mid-depth, and 1 foot from bottom, here designated as the deep sample. In the lakes with maximum depths in the range of 15 to 30 feet, water samples were obtained from surface and deep locations. In all other cases, only water samples from the surface were collected.

For measuring the secchi disc transparencies, an 8-inch diameter secchi disc with black and white quadrant markings attached to a calibrated line was used. The disc was lowered until it disappeared from view and the depth of immersion of the disc was noted. The disc was lowered farther and then raised slowly until it reappeared. The depth of immersion was noted. The average of these two observations was recorded as the secchi disc reading.

In situ dissolved oxygen and temperature measurements were made with a galvanic cell oxygen analyzer equipped with a thermister. An oxygen meter, Yellow Spring Instrument Company model 54, with a 50-foot probe lead was used for this purpose. At the beginning of each day's field survey, the probe was standardized in lake surface water in which the dissolved oxygen content was determined by a modified Winkler Method as outlined by the American Public Health Association (1971). Temperature and dissolved oxygen

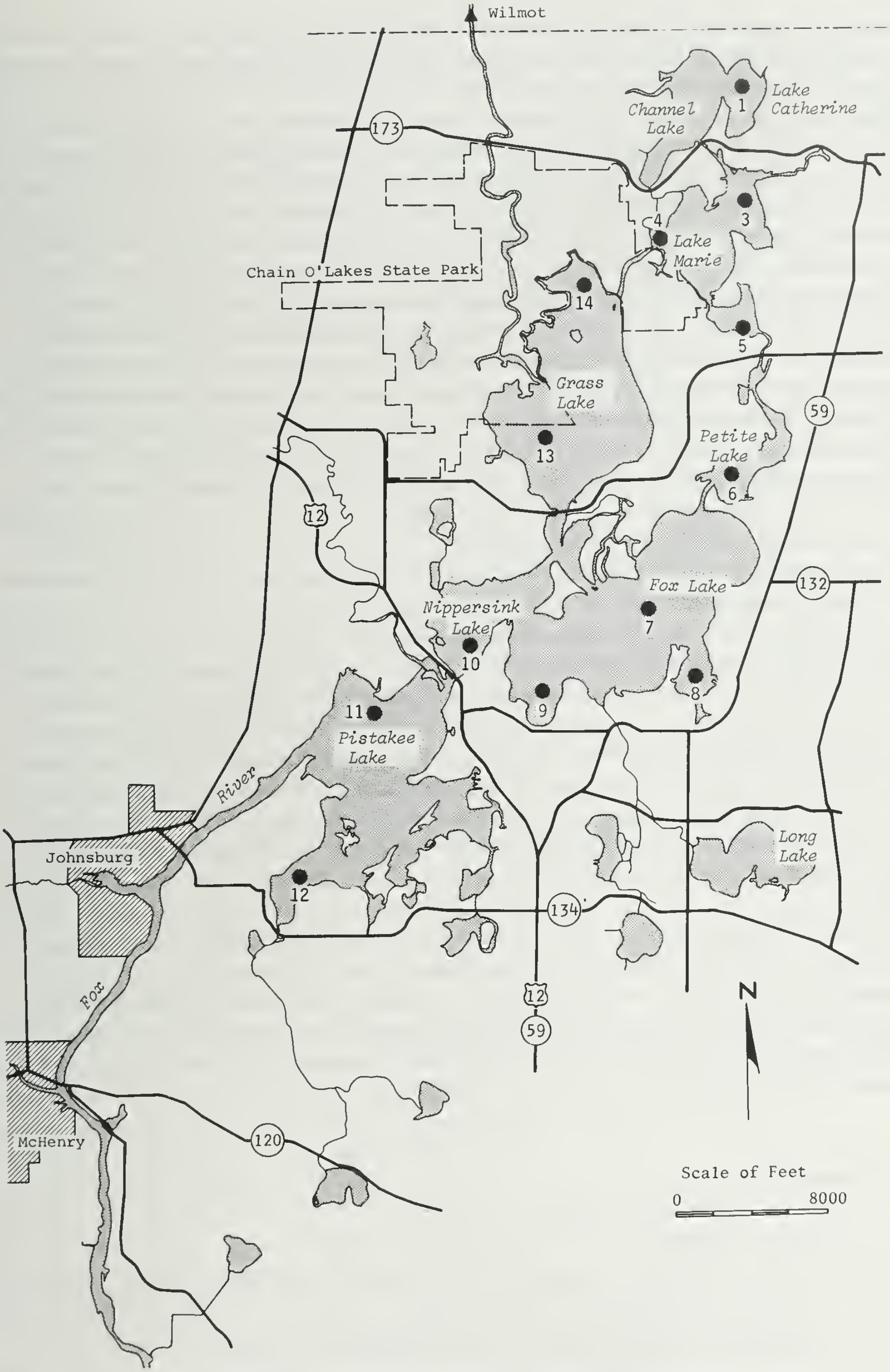

Figure 72. Locations of *in situ* sediment oxygen demand measurements

measurements were obtained at 2-foot intervals commencing from the surface of the lake. Observations were made at 1-foot intervals in the zone of the thermocline of deep lakes and in the lakes less than 15 feet deep.

Water samples for chemical analyses were collected at required depths in plastic bottles, stored on ice until transported to the laboratory, and refrigerated until chemical analyses were performed. For ammonia determinations, 50 milliliters (ml) of water samples were filtered through type HA, 0.45 μ millipore filters 37 millimeters (mm) in diameter. The filters were placed over filter pads which were held between two-piece circular holders. A set of eight such holders were held in a wooden frame designed and fabricated at the Survey laboratory. Positive pressure for filtering the samples was provided by a syringe to force the sample through the filters. The filtrates were collected in small plastic bottles. Micropore filtration eliminates any bacterial activity which could alter the ammonia concentration in the collected samples. Laboratory tests extending over a period of 4 weeks indicated that the ammonia concentrations remained stable in the filtered samples. This method of sample preservation is considered superior to acidification or other chemical additives.

Water samples in a volume of 380 ml were collected for algal identification and enumeration. These samples were preserved with 20 ml of formalin at the time of collection and stored at room temperature until examined.

Water samples, for chemical and algal analyses representative of the desired depths of the water column, were obtained with a Kemmerer water sampler.

In addition to collecting water samples and making *in situ* measurements of temperatures and dissolved oxygen concentrations in the Fox Chain of Lakes, measurements and sample collections were made in Cedar Lake. This lake is located about 4 miles east of the Fox Chain. It has been classified as a mesotrophic lake in the National Eutrophication Survey (US Environmental Protection Agency, 1975a). A comparison of the limnological characteristics of Cedar Lake with those of Fox Chain of Lakes was thought desirable. Cedar Lake was visited on a biweekly basis from July 14 to October 20, 1975. The depth at the sampling site was 42 feet. *In situ* measurements of temperature, dissolved oxygen, and secchi disc readings were made, and water samples were collected from surface, mid-depth, and deep water strata.

The following physical and chemical determinations were made on water samples in the laboratory: turbidity, pH, alkalinity, hardness, nitrate-nitrogen, Kjeldahl nitrogen, ammonia-nitrogen, total silica, total iron, chloride, sulfate, total solids, dissolved solids, suspended solids, algal growth potential (AGP), total phosphorus, and dissolved orthophosphorus. The methods and procedures involved in these determinations were discussed at the beginning of Part 3 of this report.

Physical Characteristics

Temperature and Dissolved Oxygen

Lakes in the temperate zone generally undergo seasonal variations in temperature through the water column (Kothandaraman and Evans, 1970). These variations, with their accompanying phenomena, are perhaps the most influential controlling factors within the lakes.

The temperature of a deep lake in the temperate zone is about 4°C during early spring. As the air temperatures rise, the upper layers of water warm up and mix with the lower layers by wind action. By late spring, the differences in thermal resistance cause the mixing to cease and the lake approaches the thermal stratification of the summer season. Following closely the temperature variation in water is the physical phenomenon of increasing density with decreasing temperature up to a certain point. These two interrelated forces are capable of creating within the lake strata of water of vastly differing characteristics.

During thermal stratification the upper layer (the epilimnion) is isolated from the lower layer of water (the hypolimnion) by a temperature gradient (the thermocline). Temperatures in the epilimnion and hypolimnion are essentially uniform. The thermocline will typically have a sharp temperature drop per unit depth from the upper to the lower margin. When the thermal stratification is established, the lake enters the summer stagnation period, so named because the hypolimnion becomes stagnated.

With cooler air temperatures during the fall season, the temperature of the epilimnion decreases. This decrease in temperature continues until the epilimnion is the same temperature as the upper margin of the thermocline. Successive cooling through the thermocline to the hypolimnion results in a uniform temperature through the water column. The lake then enters the fall circulation period, called 'fall turnover' and is again subjected to a complete mixing by the wind.

Declining air temperatures and the formation of an ice cover during the winter produce a slight inverse thermal stratification (Fair et al., 1963). The water column is essentially uniform in temperature at about 3 to 4°C but slightly colder temperatures of 0 to 2°C prevail just below the ice. With the advent of spring and gradually rising air temperatures, the ice begins to disappear, and the temperature of the surface water rises. The lake again becomes uniform in temperature and the spring circulation occurs.

The most important phase of the thermal regime from the standpoint of eutrophication is the summer stagnation period. The hypolimnion, by virtue of its stagnation, traps sediment materials such as decaying plant and animal matter thus decreasing the availability of nutrients during the critical growing season. In an eutrophic lake, the hypolimnion becomes anaerobic or devoid of oxygen because of the increased content of highly oxidizable material and because of its isolation from the atmosphere. In the absence of oxygen, the conditions for chemical reduction become favorable and more nutrients are released from the bottom sediments to the overlying waters.

However, during the fall circulation period, the lake water becomes mixed, and the nutrient rich hypolimnetic waters are redistributed. The nutrients which remained trapped during the stagnation period become available during the following growing season. Therefore, a continual supply of plant nutrients from the drainage basin is not mandatory for sustained plant production. Fruh (1967) and Fillos and Swanson (1975) stated that after an initial stimulus, the recycling of nutrients within a lake might be sufficient to sustain highly productive conditions for several years.

Figures 73 through 80 show the isothermal plots for the lake system with depths of 17 feet or more. At the time of the first observation for temperature profiles, on May 19, 1975, the deep lakes in the Fox Chain had already begun to stratify. In the case of Lake Bloomington, in central Illinois, thermal stratification was found to set in during mid-June (Kothandaraman and Evans, 1970).

The lake surface water temperatures in the Fox Chain increased gradually reaching a maximum of about 29°C on August 4, 1975, and decreased gradually from then on. In all the lakes, the depth of epilimnetic zone at the time of peak stratification was found to be confined to the upper 15 feet.

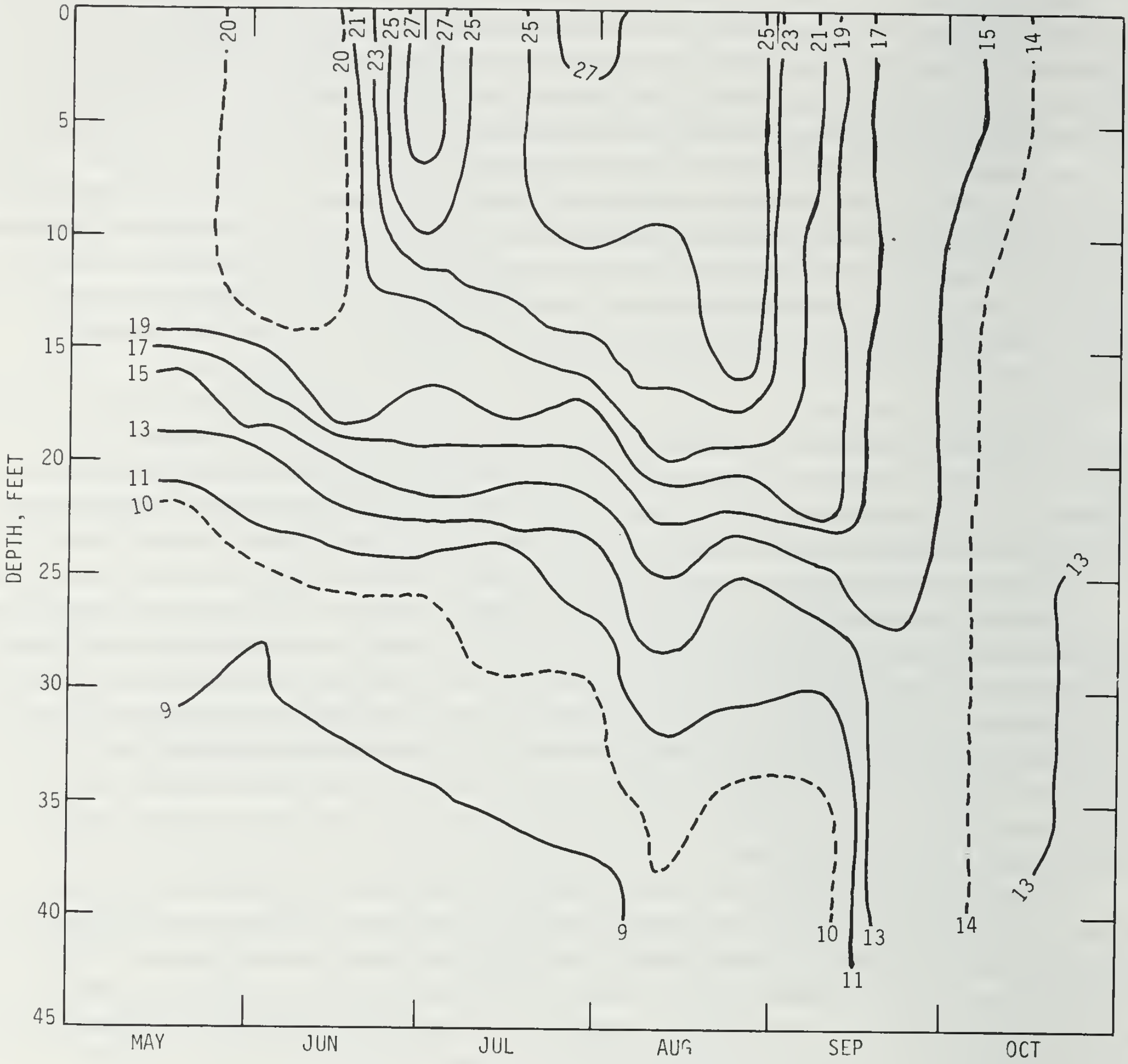

Figure 73. Isothermal plots for Lake Catherine

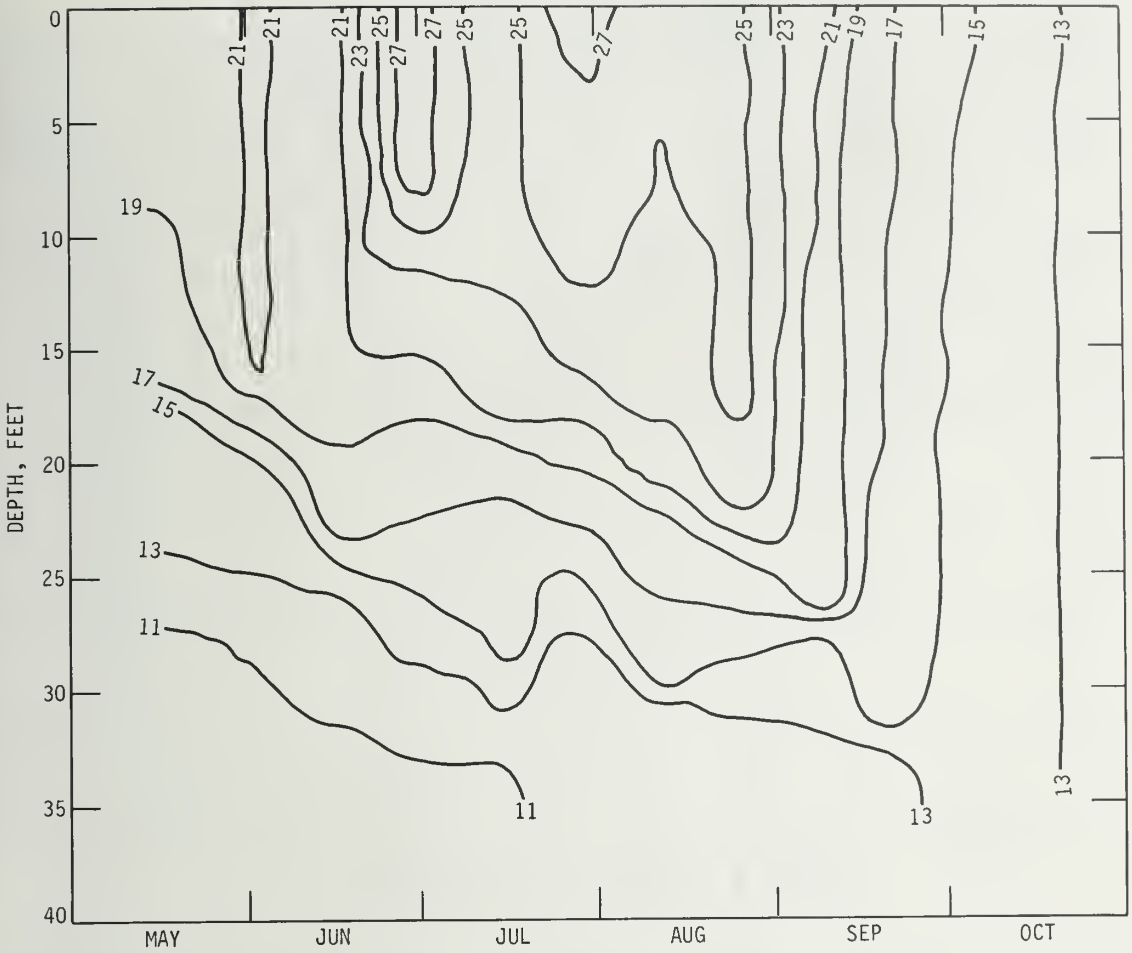

Figure 74. Isothermal plots for Channel Lake

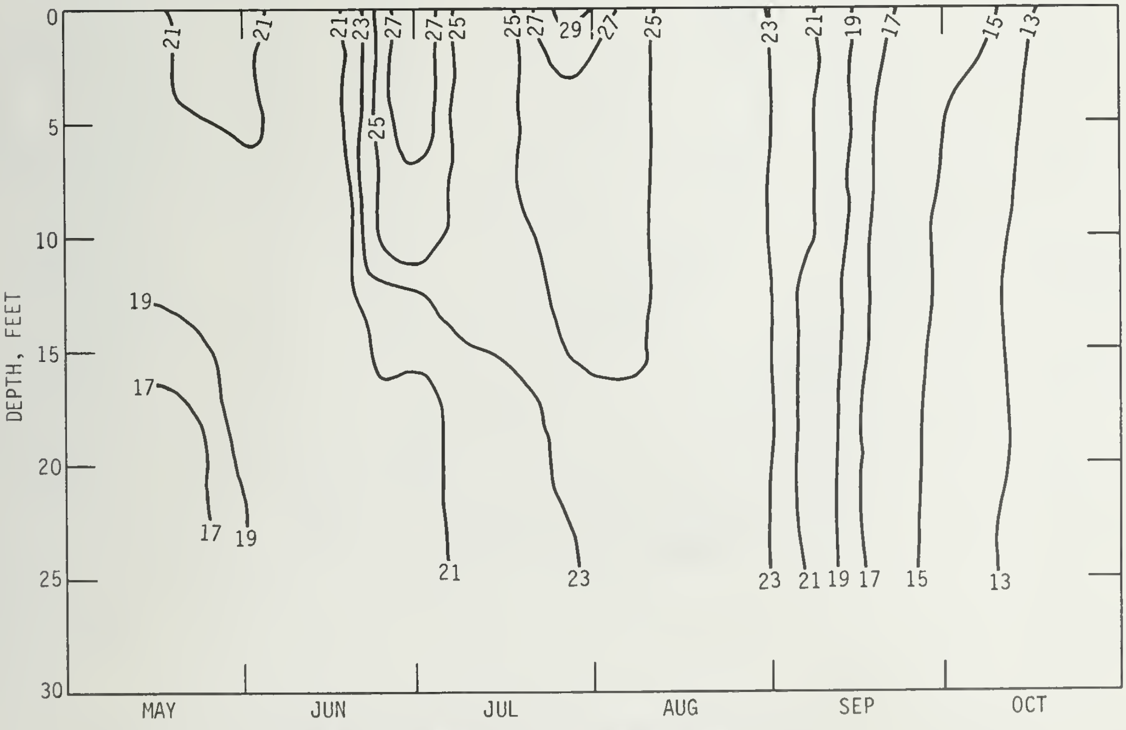

Figure 75. Isothermal plots for Lake Marie (east basin)

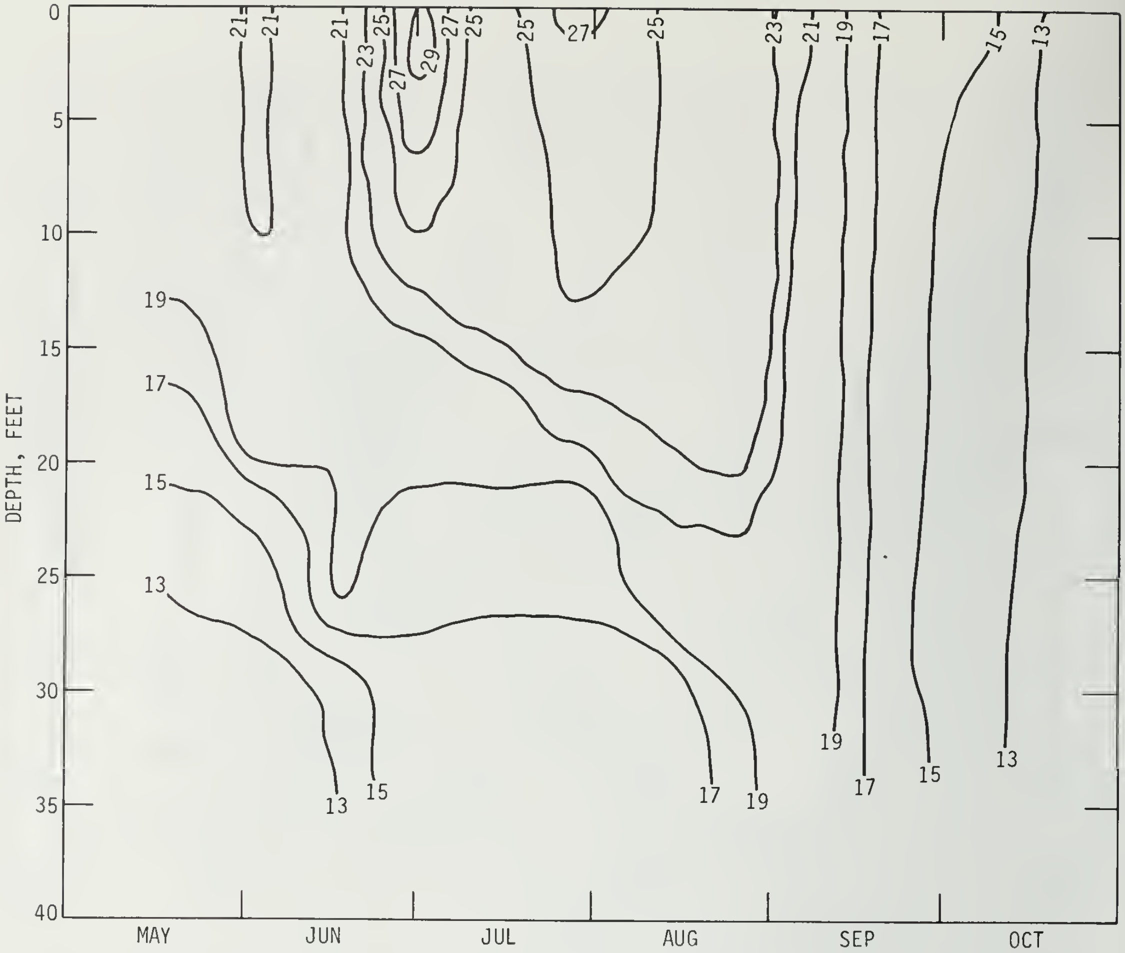

Figure 76. Isothermal plots for Lake Marie (west basin)

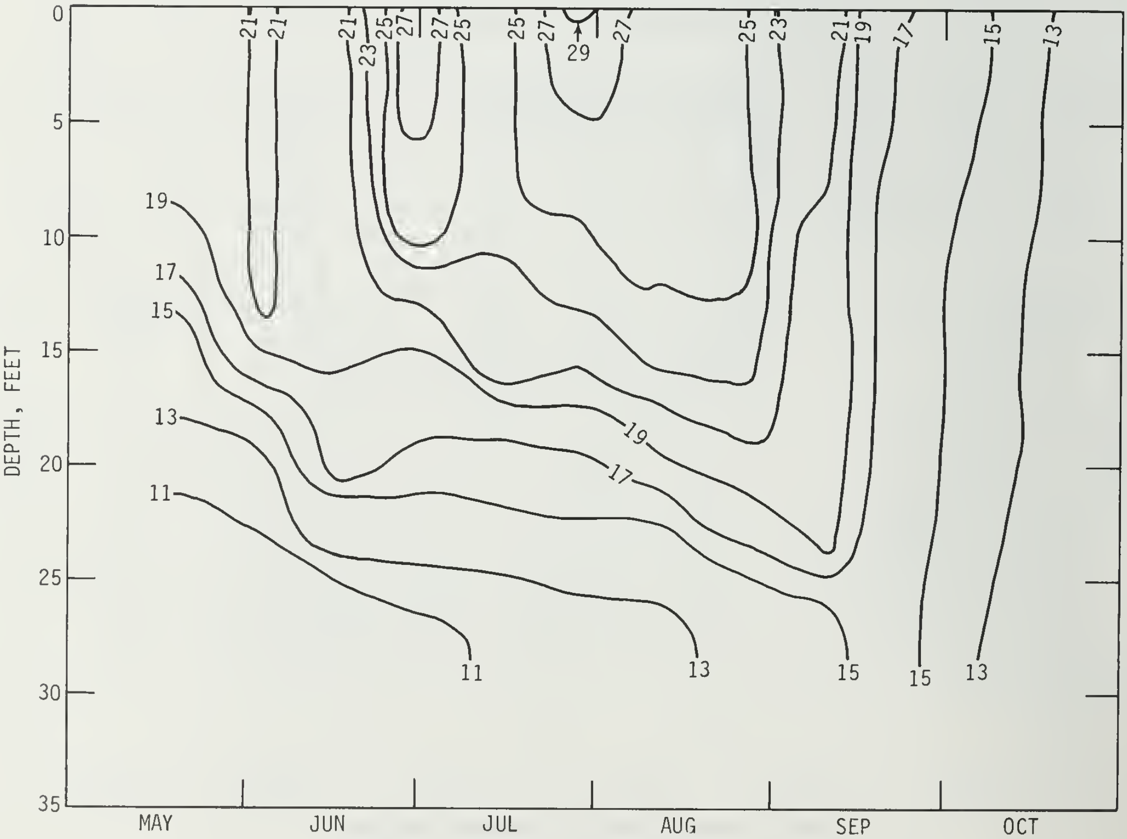

Figure 77. Isothermal plots for Bluff Lake

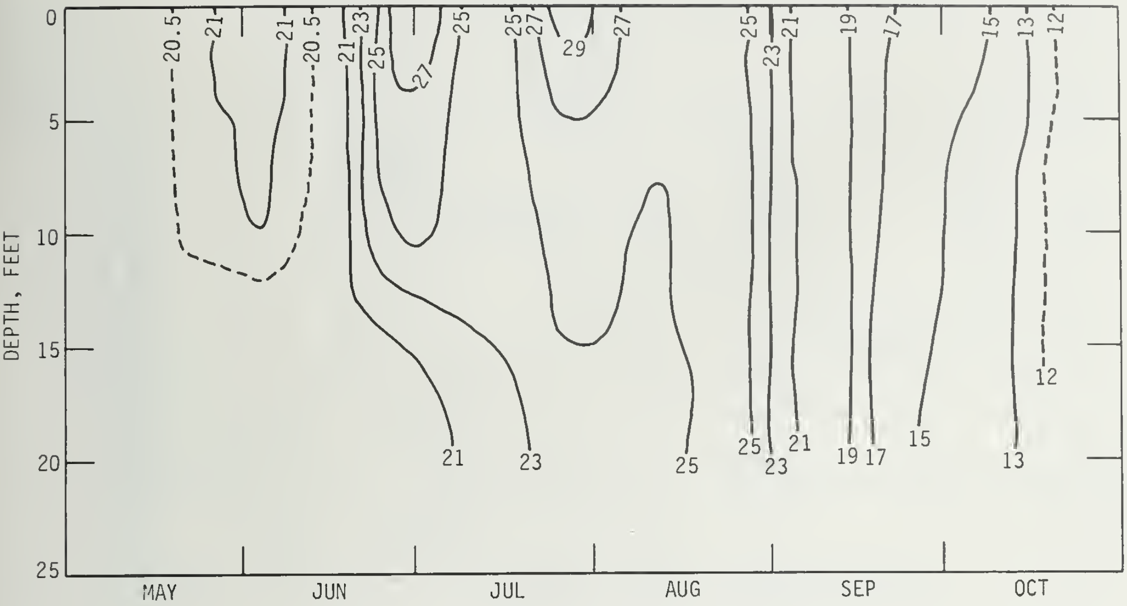

Figure 78. Isothermal plots for Petite Lake

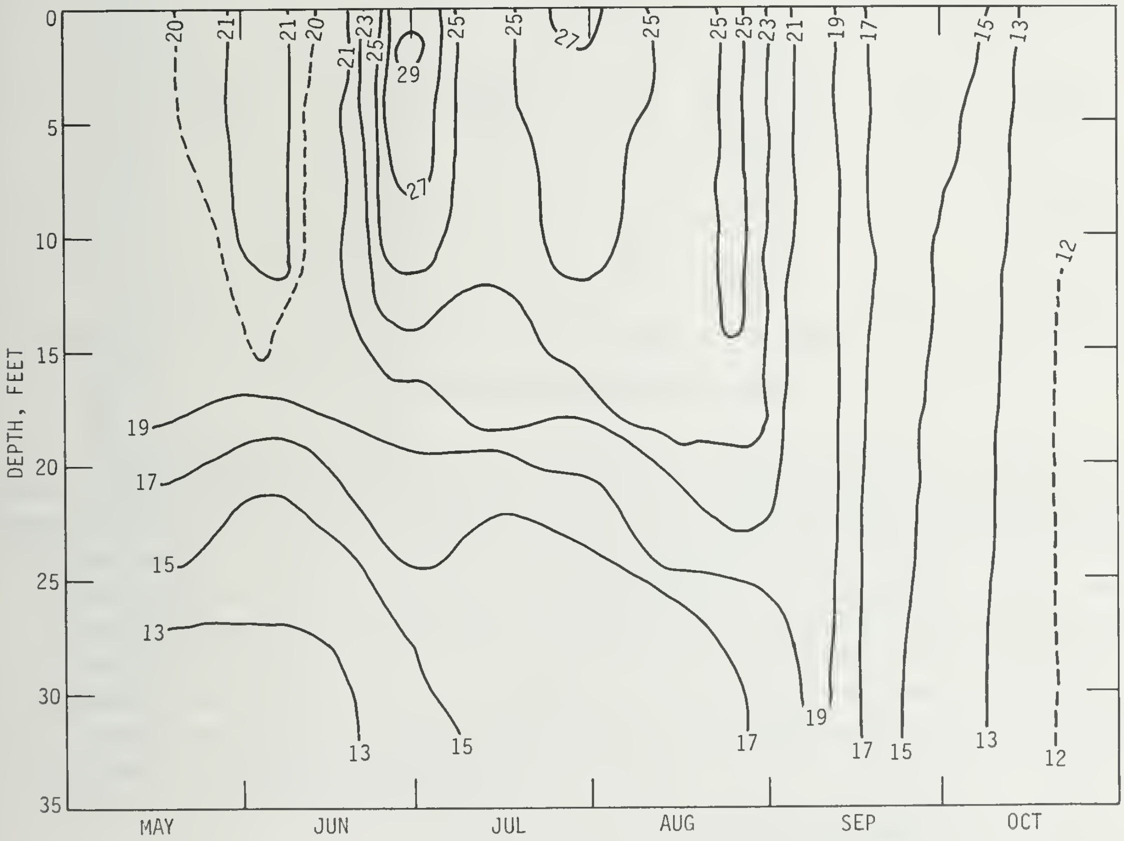

Figure 79. Isothermal plots for Pistakee Bay

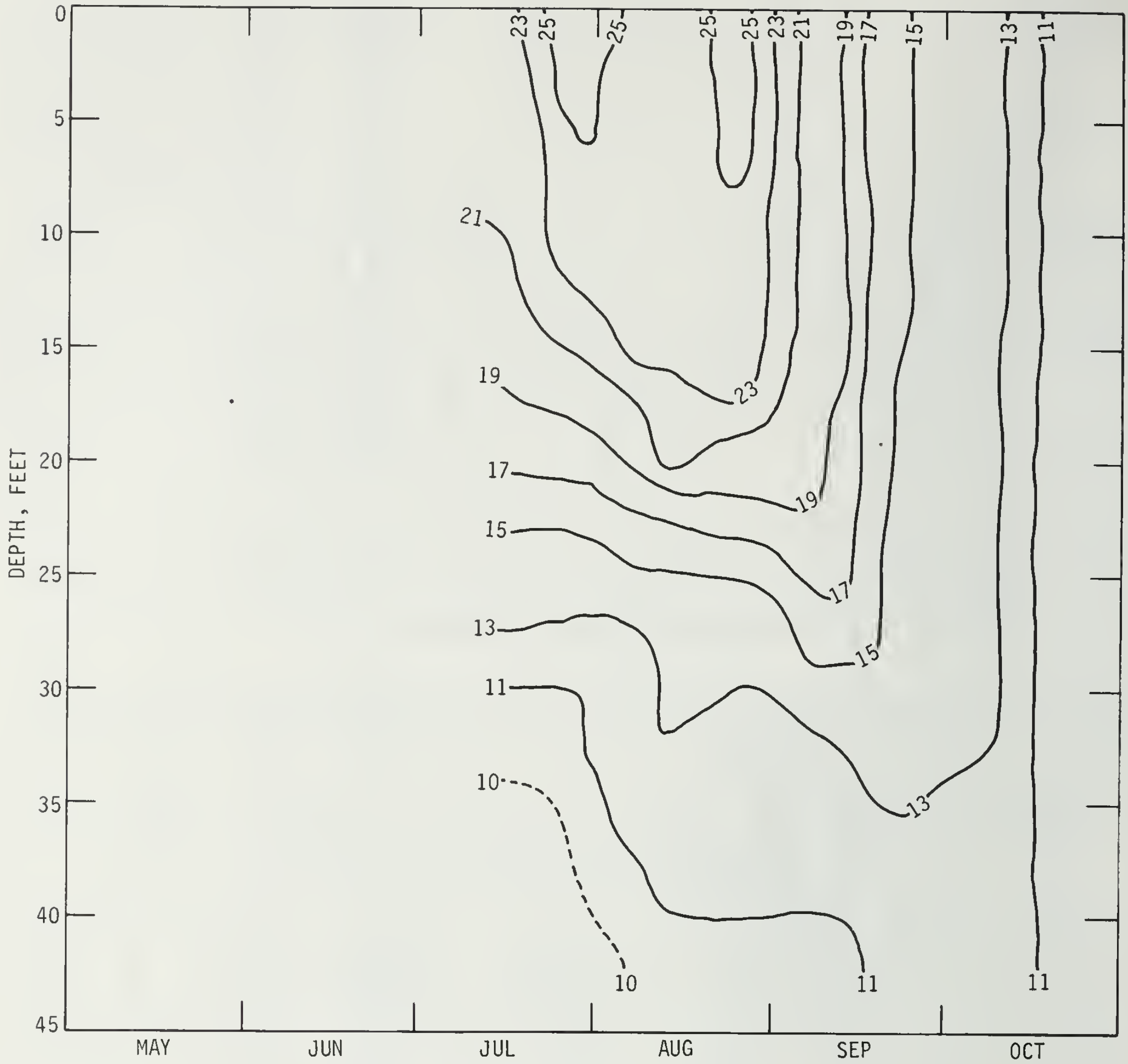

Figure 80. Isothermal plots for Cedar Lake

The deep water temperatures in the lakes varied depending on the depth of the lakes. For instance, in Lake Catherine and Cedar Lake (figures 73 and 80, respectively), which are the two deepest of all the lakes investigated, the water strata adjacent to the bottom ranged from 9 to 11°C during the period of summer stagnation. Deep strata water temperatures in shallower lakes were higher. Likewise, the deepest lakes destratified later than the shallow ones. Lake Catherine and Cedar Lake destratified in late September, whereas in Channel Lake, Lake Marie (west basin), and Bluff Lake (figures 73, 75, and 76, respectively), the fall circulation occurred in the early part of September. This group of lakes has a maximum depth of about 30 feet. The phenomenon of thermal stratification was not pronounced in Lake Marie (east basin) nor in Petite Lake where the maximum depths are only about 20 feet. In these two lakes only, a temperature gradient existed from top to bottom without any well-defined thermal stratification.

Figures 81 through 87 show the temperature and dissolved oxygen profiles in Fox Lake and its two bays and in Nippersink, Pistakee, and Grass Lakes. These lakes are relatively shallow with maximum observed depths of less than 15 feet. The temperature profiles are

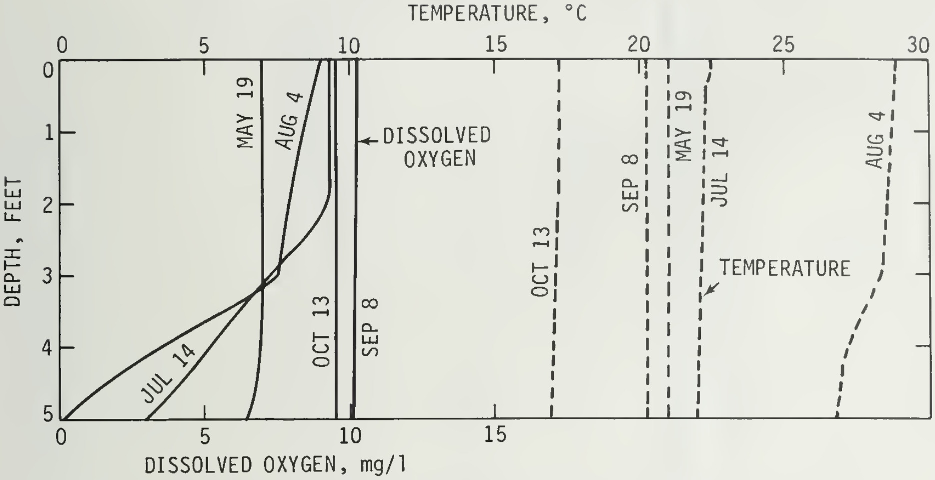

Figure 81. Temperature and dissolved oxygen profiles in Fox Lake (Stanton Bay)

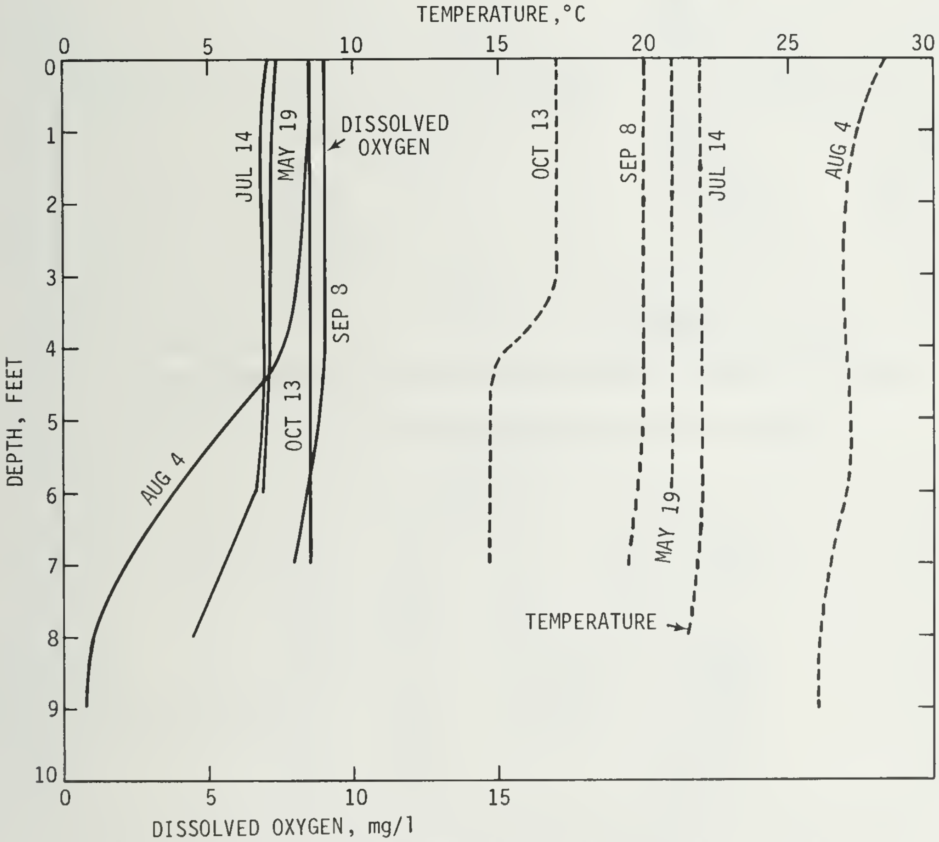

Figure 82. Temperature and dissolved oxygen profiles in Fox Lake (main body)

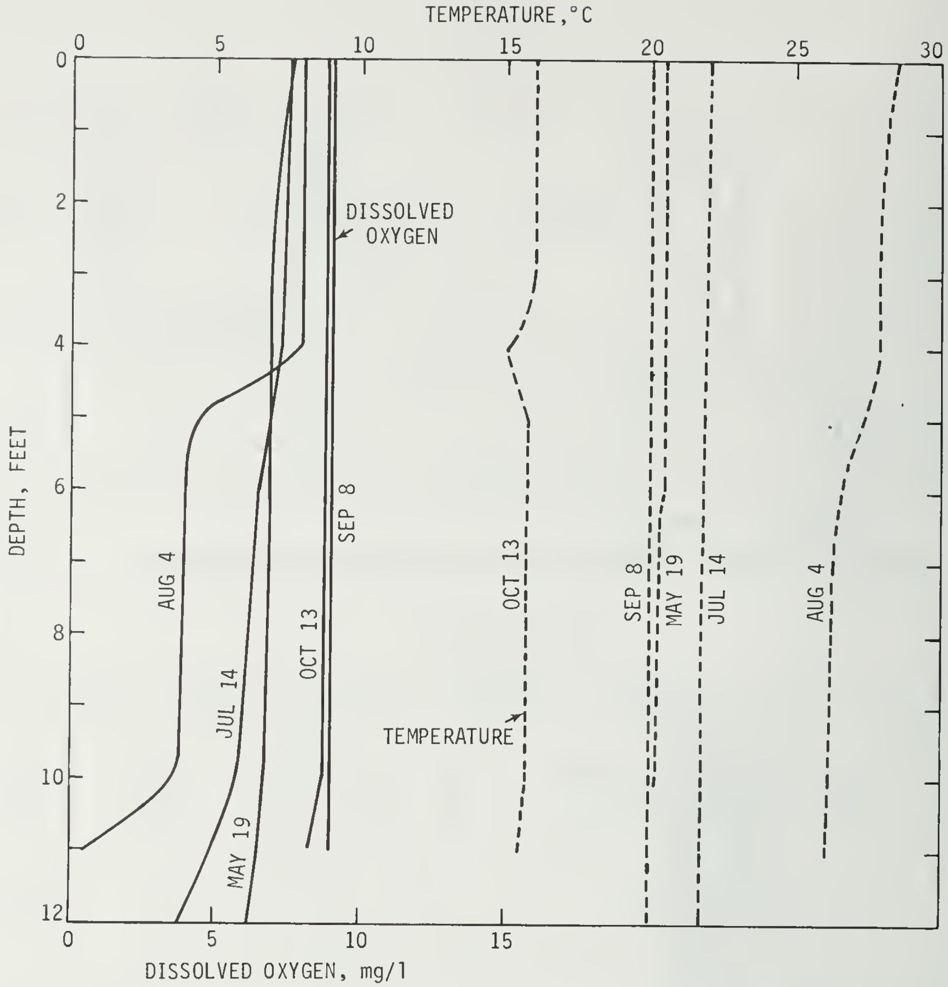

Figure 83. Temperature and dissolved oxygen profiles in Fox Lake (Mineola Bay)

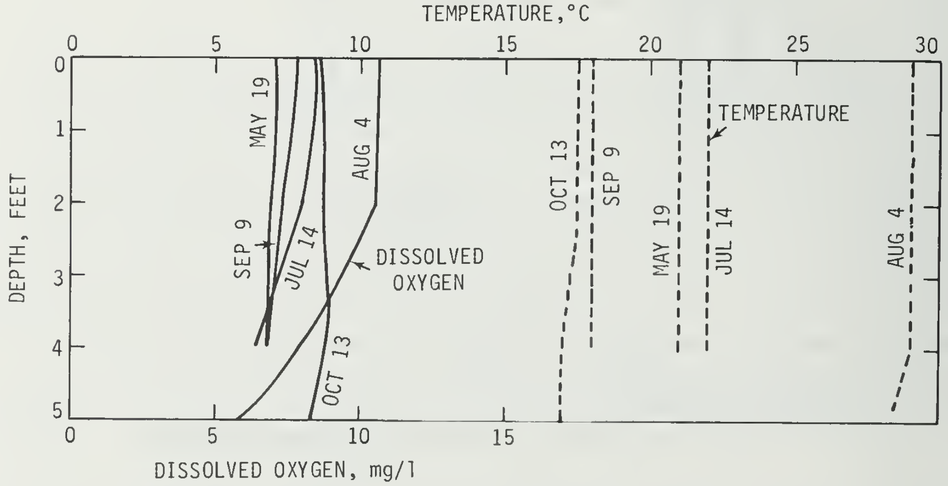

Figure 84. Temperature and dissolved oxygen profiles in Nippersink Lake

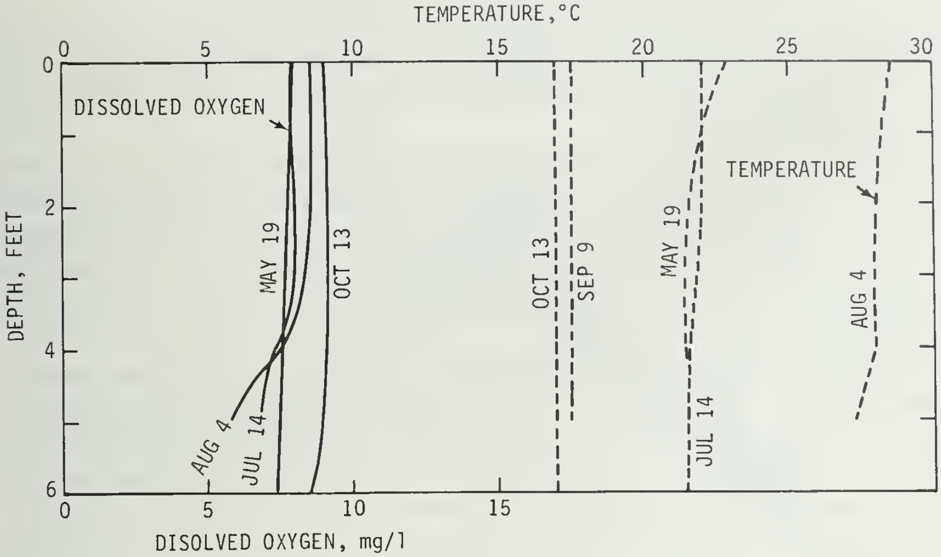

Figure 85. Temperature and dissolved oxygen profiles in Pistakee Lake

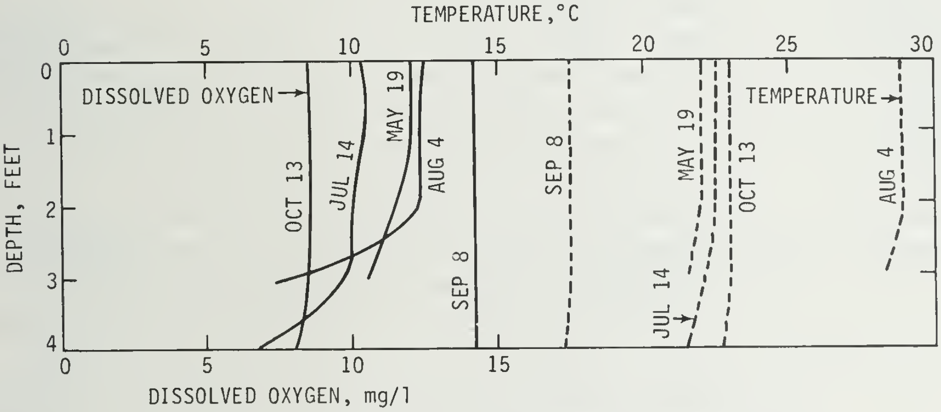

Figure 86. Temperature and dissolved oxygen profiles in Grass Lake (south)

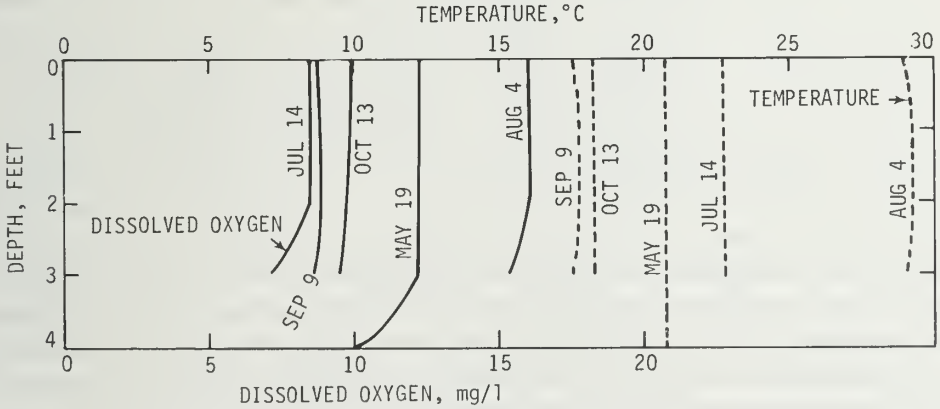

Figure 87. Temperature and dissolved oxygen profiles in Grass Lake (north)

plotted for five different dates. The surface water temperatures reached a maximum of about 29°C on August 4. Because the lakes are shallow, they are completely mixed, both by wind action and by the intense boating activities in these lakes. Thermal gradients in these lakes are very insignificant.

On the basis of the data collected in the Fox Chain of Lakes, it can be concluded that the upper deep lakes in the Chain stratify thermally and, at the period of peak stagnation, the epilimnetic zone is only 15 feet deep. In the lakes with maximum observed depths of about 20 feet, no well-defined thermal stratification existed. However, a perceptible degree of temperature gradient existed. In shallow lakes with depths less than 15 feet, the entire water mass was thermally uniform.

It is common knowledge that the impoundment of water, natural or man-made, alters its physical, chemical, and biological characteristics. The literature is replete with detailed reports on the effects of impoundments on various water quality parameters. The physical changes in the configuration of the water mass following impoundment reduce reaeration rates to a small fraction of those of free flowing streams. Where the depth of impoundment is considerable, the thermal stratification acts as an effective barrier for the wind-induced mixing of the hypolimnetic zone. The oxygen transfer to the deep waters is essentially confined to the molecular diffusion transport mechanism.

During the period of summer stagnation and increasing water temperatures, the bacterial decomposition of the bottom organic sediments exerts a high rate of oxygen demand on the overlying waters. When this rate of oxygen demand exceeds the oxygen replenishment by molecular diffusion, anaerobic conditions begin to prevail in the zones adjacent to the lake bottom. Hypolimnetic zones of man-made impoundments were also found to be anaerobic within a year of their formation (Kothandaraman and Evans, 1975).

The isopleth plots of dissolved oxygen for Lake Catherine are shown in figure 88. At the beginning of the field investigation, the lake waters were anoxic from depths of approximately 30 to 40 feet. As the summer stagnation intensified, the anoxic zone of hypolimnetic waters increased progressively reaching a maximum by the end of July. The extent of this anaerobic zone started diminishing thereafter and the DO concentration became uniform in the entire water column by mid-October. It must be pointed out that the progression of this anoxic zone coincided with the progression of the thermal stratification in the lake. At the time of peak thermal stratification, about 980 acre-feet or 40 percent of the lake volume was devoid of oxygen. At that time, only the epilimnetic zone, about 15 feet deep, had acceptable levels of dissolved oxygen.

Other deep lakes in the Fox Chain of Lakes system exhibited similar trends. The dissolved oxygen isopleths for these deep lakes are shown in figures 89 through 95. Even though no well-developed thermal stratification existed in Petite Lake, isopleth plots of dissolved oxygen for this lake shown in figure 93 indicate that there were periods when the water layers adjacent to the lake bottom were totally devoid of oxygen. Such episodes must have occurred during the absence of wind-induced mixing. Also in Cedar Lake (figure 95), which is classified as a mesotrophic lake, hypolimnetic waters from depths below 25 feet were anaerobic. All the deep water samples collected from lakes with depths of 30 feet or more, with the exception of Cedar Lake, had a strong septic odor predominantly that of hydrogen sulfide. The maximum extent of the anoxic zones in these lakes is shown in table 39. It is apparent that significant portions of the deep lakes are anoxic, particularly in Lake Catherine, Channel Lake, and Pistakee Bay.

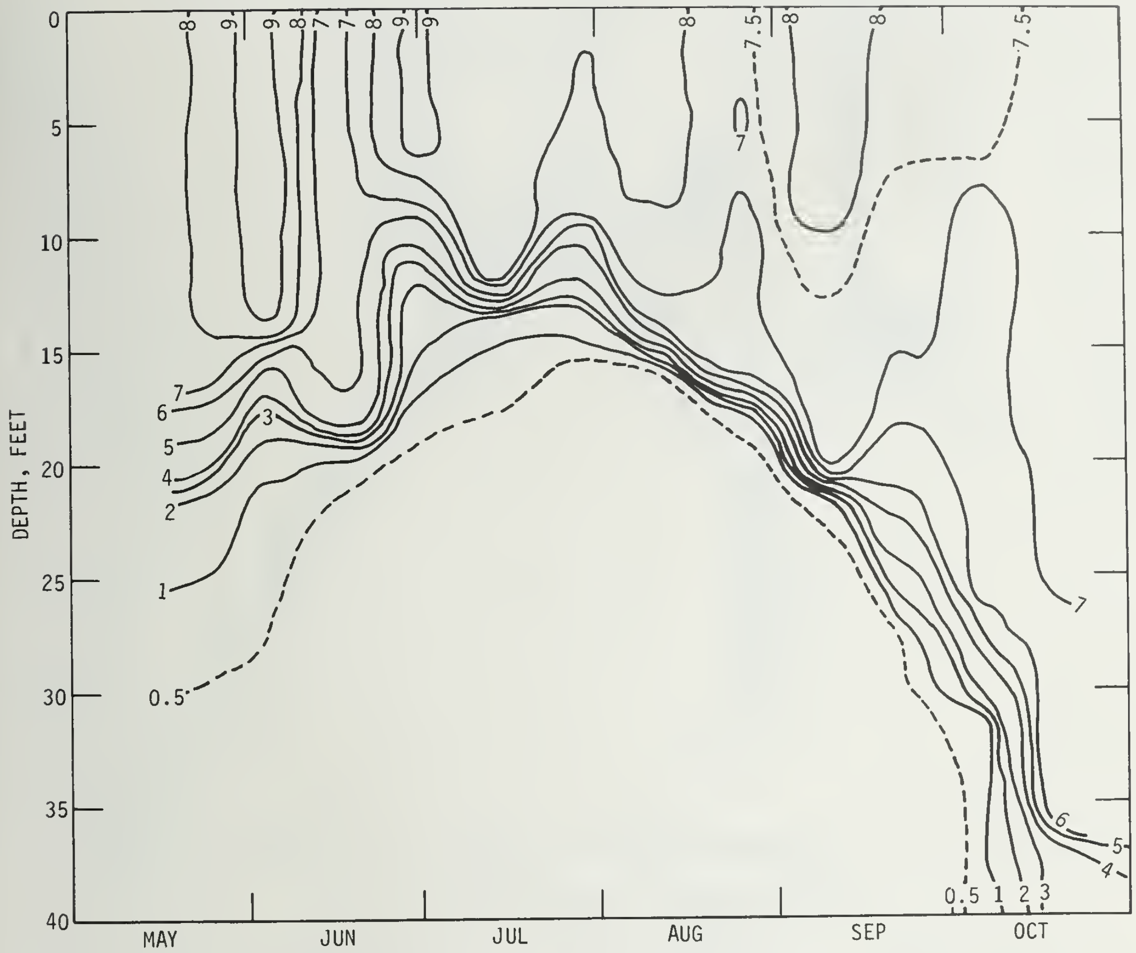

Figure 88. Isopleths of dissolved oxygen in Lake Catherine

Table 39. Extent of Anoxic Zones in Fox Chain of Lakes

Lake	*Depth to anoxic zone from surface (ft)*	*Volume of anoxic zone (acre-feet)*	*Percent of total volume*
Catherine	15	981	39.9
Channel	15	1368	31.3
Lake Marie (east basin)	15	823	17.4
Lake Marie (west basin)	15		
Bluff	15	165	17.1
Pistakee Bay	10	1025	41.6
Cedar	25		

Dissolved oxygen profiles for shallow lakes are shown in figures 81 to 87. Even though the lakes are thermally uniform, or nearly so, during the peak summer periods the oxygen demands exerted by the lake bottom sediments on the overlying waters appear to be much in excess of the oxygen replenishment from the atmosphere and algal activity. This phenomenon is much pronounced in all the shallow lakes from mid-July to mid-August, when the observed DO concentrations at 2 to 4 feet from the bottom were much less than DO concentrations in the upper layers. In order to evaluate the extent of the rate of sediment

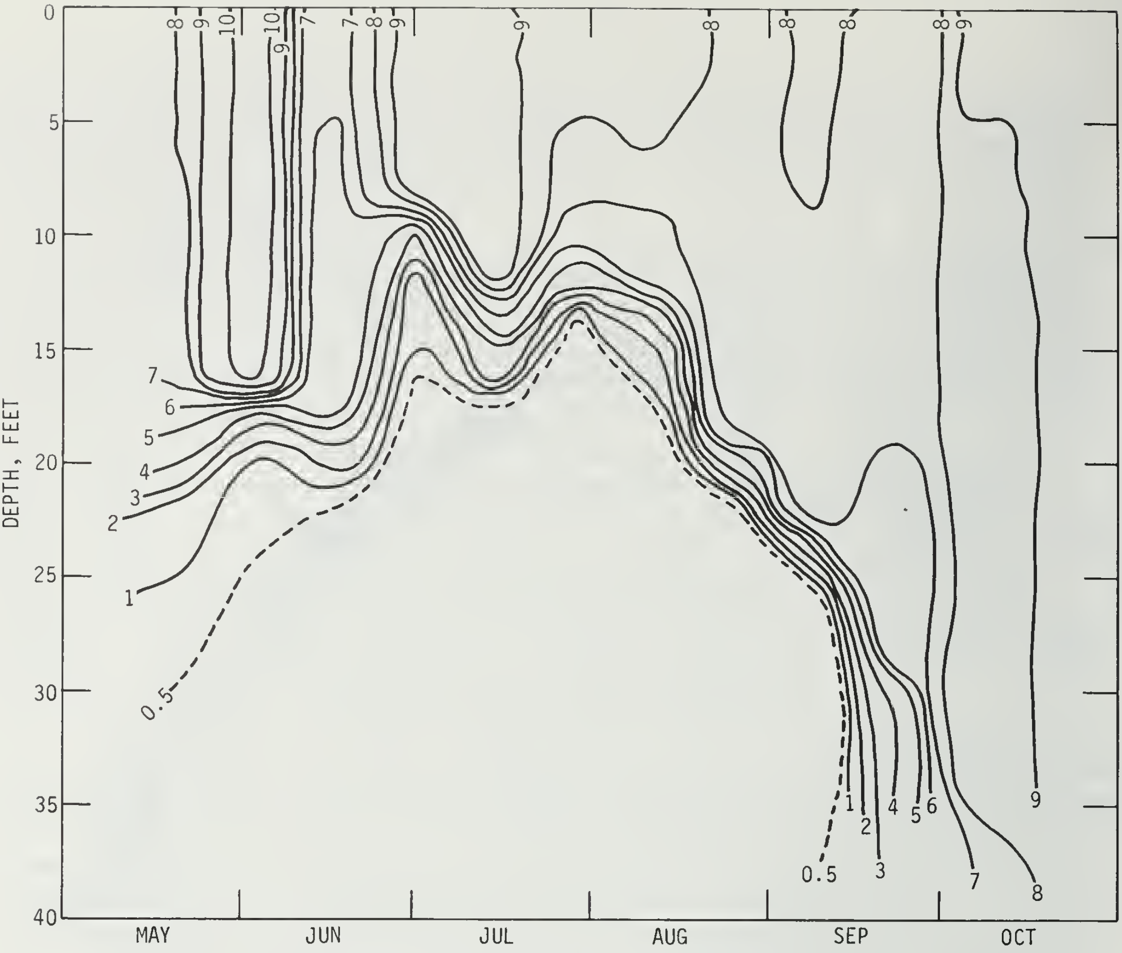

Figure 89. Isopleths of dissolved oxygen in Channel Lake

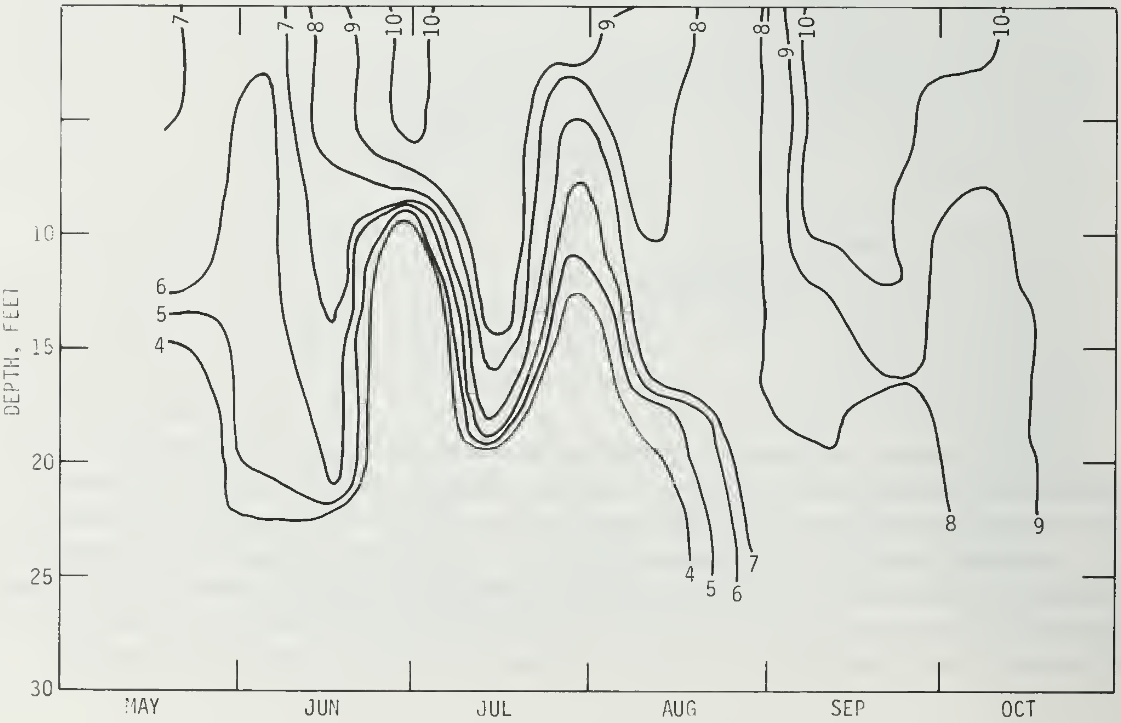

Figure 90. Isopleths of dissolved oxygen in Lake Marie (east)

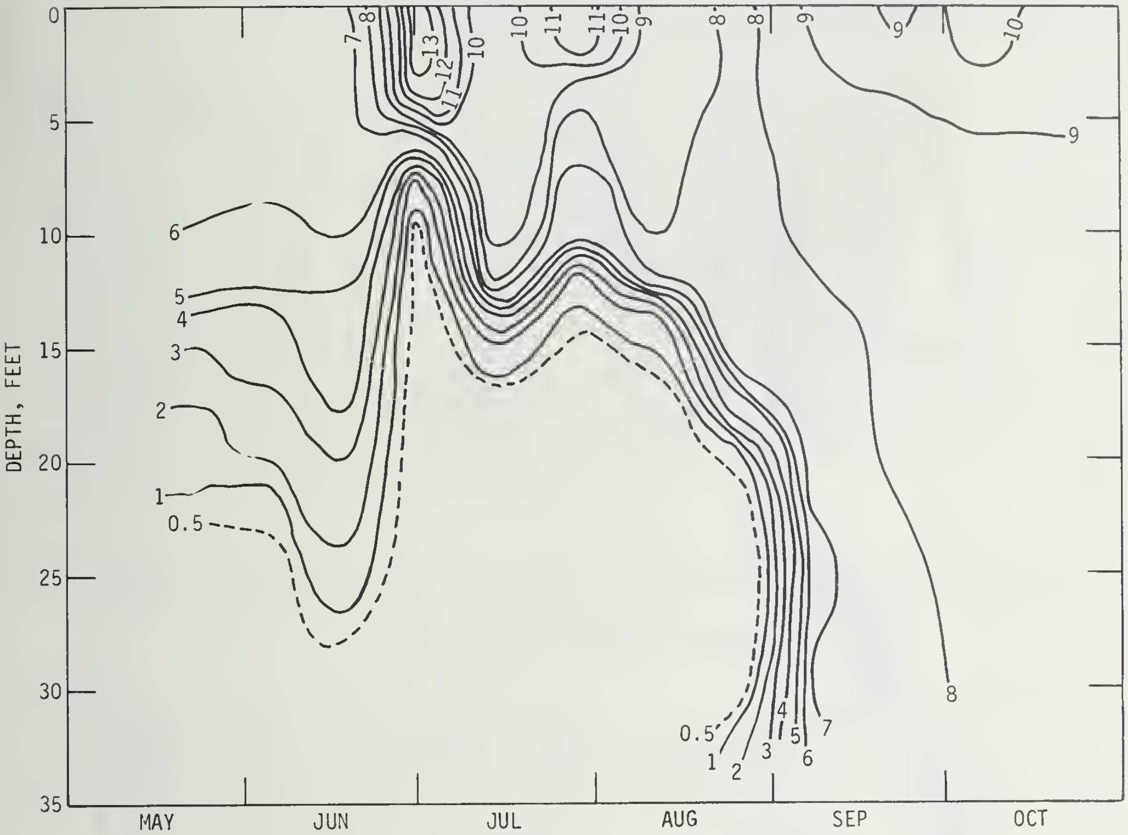

Figure 91. Isopleths of dissolved oxygen in Lake Marie (west)

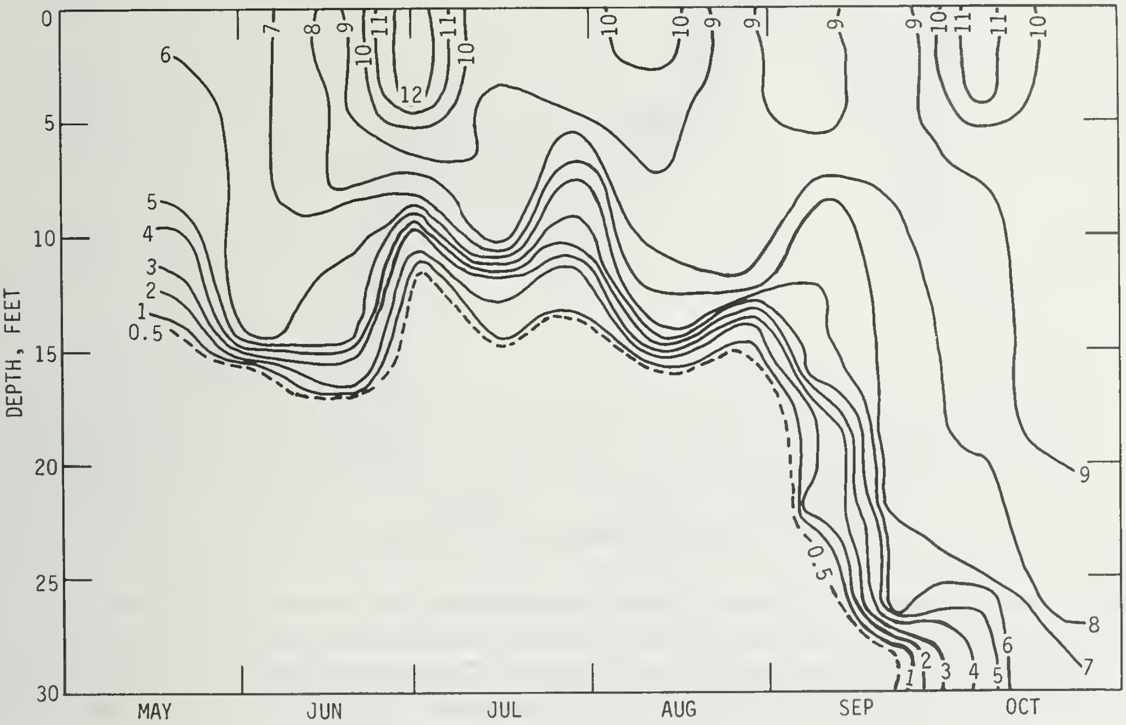

Figure 92. Isopleths of dissolved oxygen in Bluff Lake

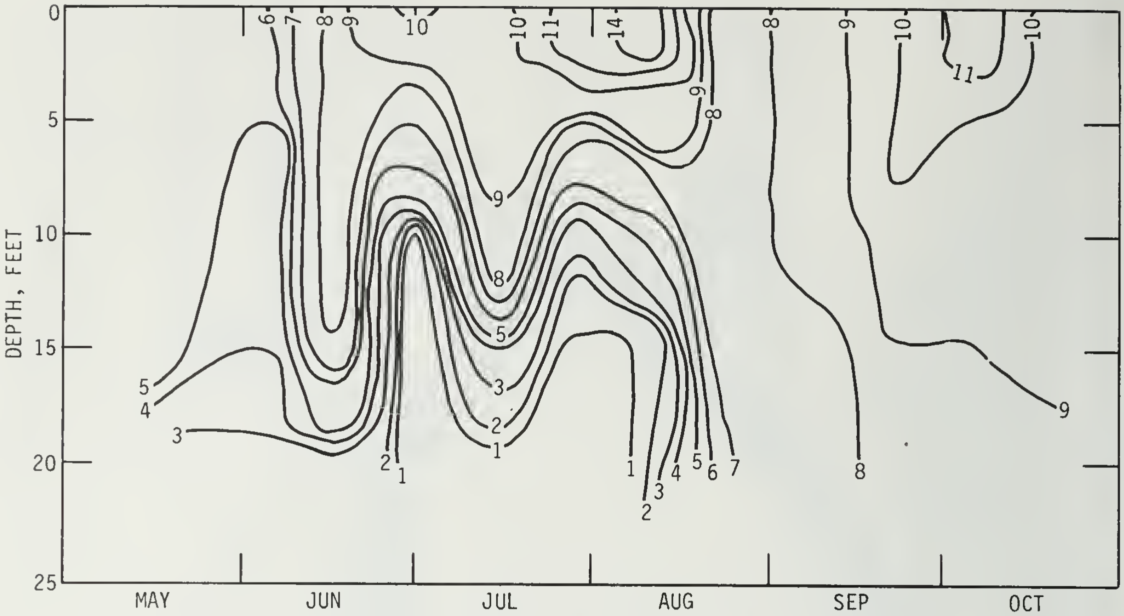

Figure 93. Isopleths of dissolved oxygen in Petite Lake

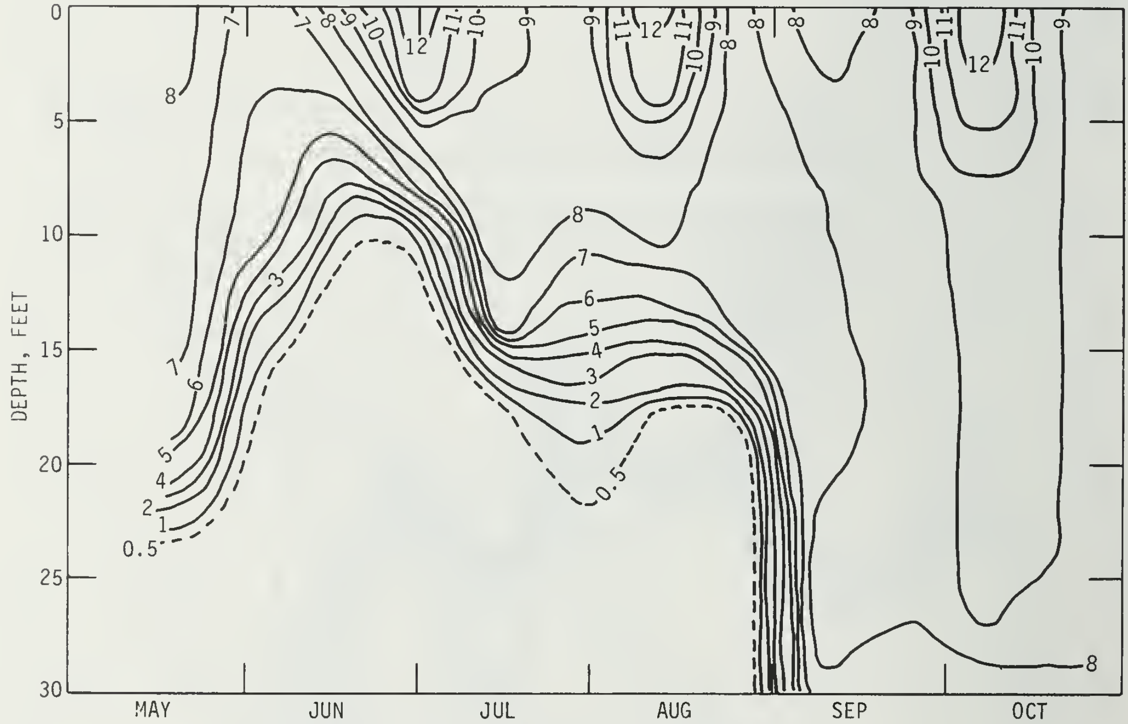

Figure 94. Isopleths of dissolved oxygen in Pistakee Bay

oxygen demand on the overlying waters, *in situ* measurements were made in these lakes. A detailed discussion on this aspect is included in the next section.

The temporal variations in the percent dissolved oxygen saturation in lake surface waters are shown in figure 96. The saturation concentrations for dissolved oxygen at the observed temperatures were computed from the following expression (Butts et al., 1973):

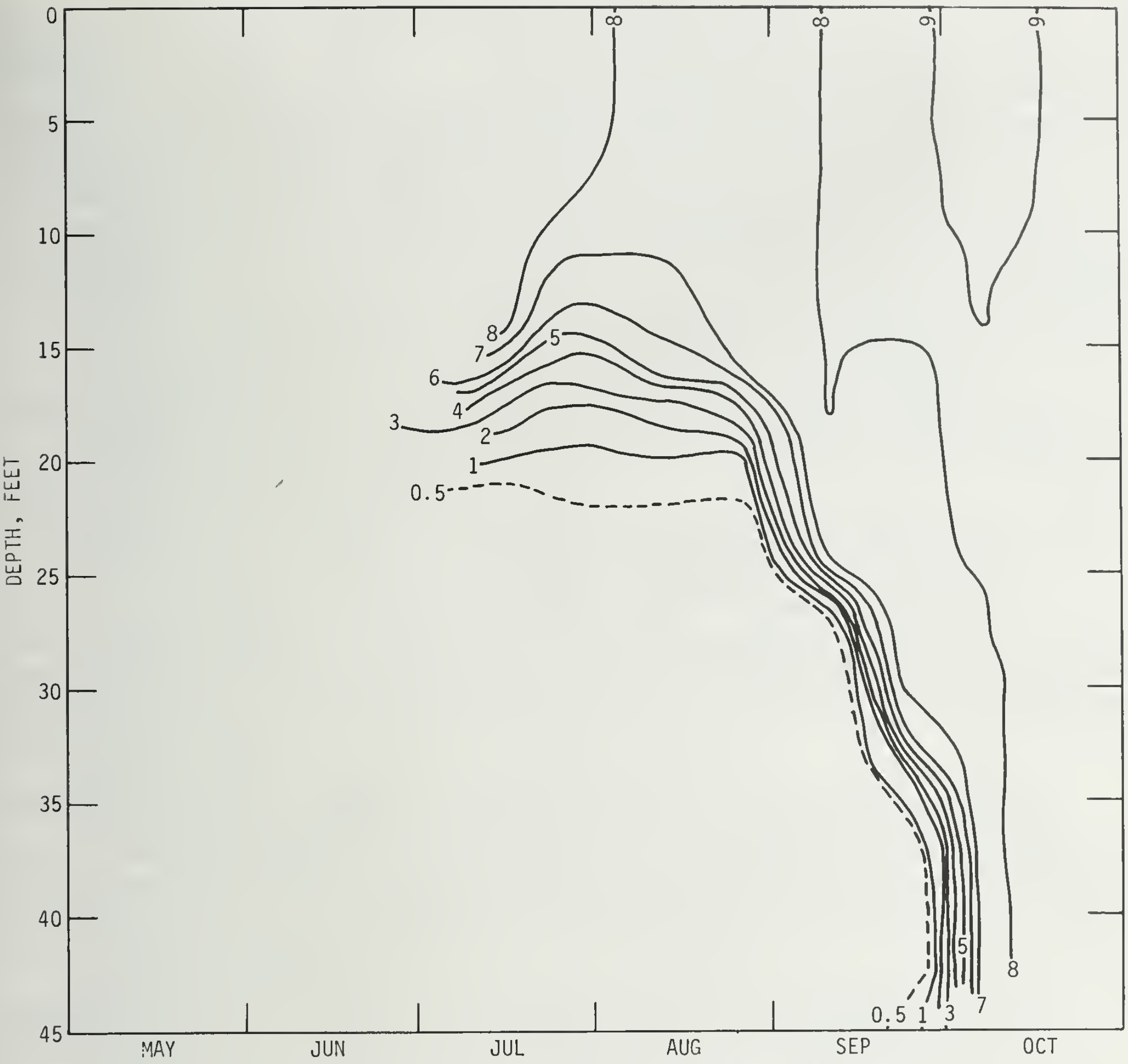

Figure 95. Isopleths of dissolved oxygen in Cedar Lake

$$DO = 14.652 - 0.41022T + 0.007991T^2 - 0.000077774T^3$$

where

DO = the dissolved oxygen, mg/l
T = water temperature, °C

At the beginning of the field investigation, the percent saturation of DO was significantly less than 100 in all the lakes with the exception of Grass Lake north and Grass Lake south (figure 96). However, supersaturated conditions prevailed during the summer months in all the lakes with the exception of Cedar Lake. The supersaturated conditions in the lakes paralleled the algal activities. Grass Lake had the highest geometric mean of algal counts, predominantly diatoms, and it remained supersaturated most of the time. The degree of supersaturation reached about 220 percent in Grass Lake and Pistakee Lake. The dissolved oxygen concentration in Cedar Lake remained near saturation or undersaturated for the entire period of field monitoring. The algal density in Cedar Lake was the lowest among the group of lakes investigated.

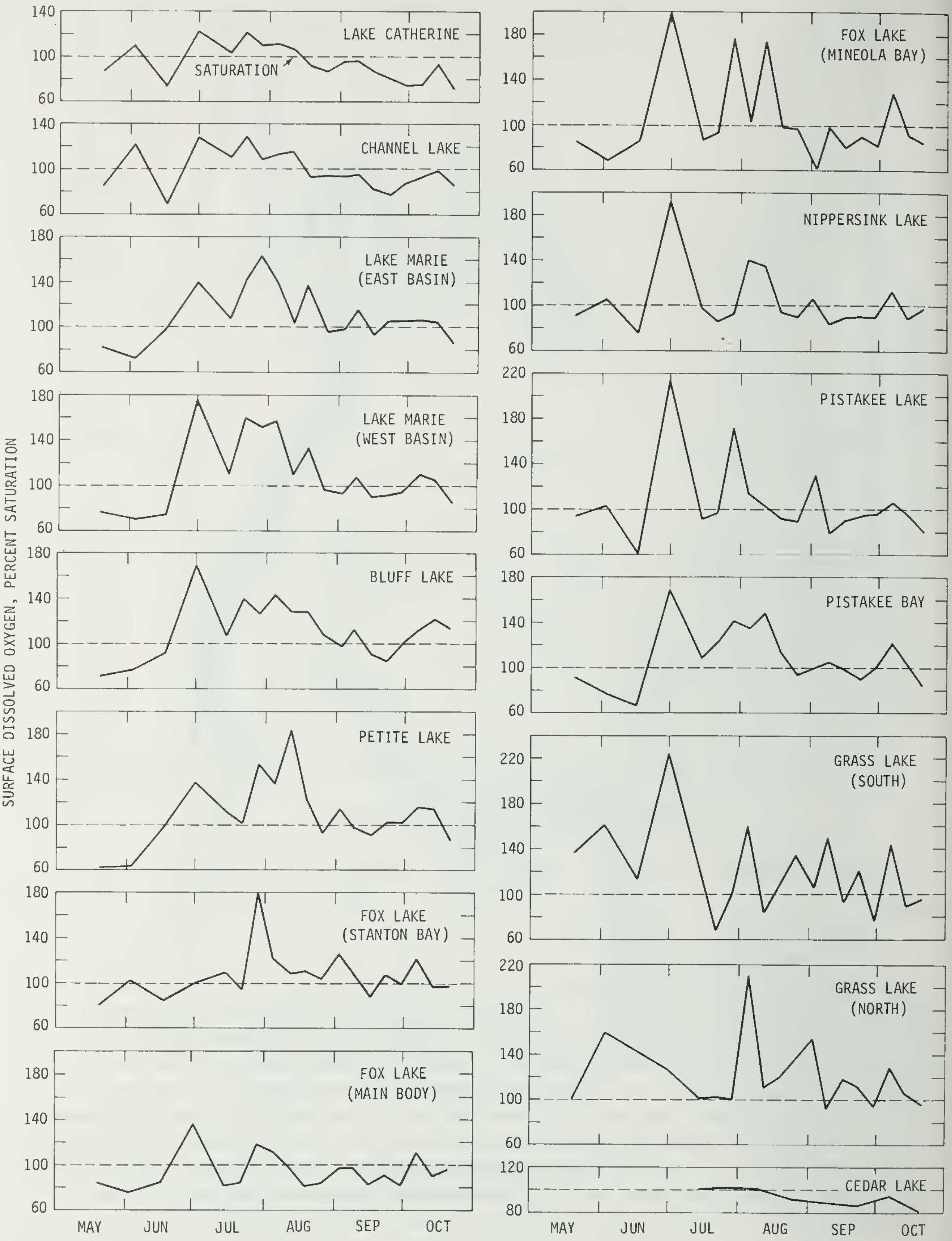

Figure 96. Lake surface dissolved oxygen, percent saturation

Sediment Oxygen Demand

In situ observations for sediment oxygen demand (SOD) rates were made with the basic techniques and equipment developed by Butts (1974). However, an improvement in the circulation equipment was implemented; the generator driven pump was replaced with a DC pump powered by a 12-volt automobile battery. A measurement was made in each lake, except for Channel Lake which was considered an extention of Lake Catherine as far as bottom sediments are concerned. Each measurement was made near the water sampling stations except for Marie (east and west) and Petite Lakes. For Lake Marie (east) measurement was made near the shallow east side; for Marie (west) and Petite Lakes measurements were made near the shallow west sides. These SOD sampling sites are shown in figure 72. Benthic sediment samples were collected in conjunction with the SOD measurements. Of interest were the consistency of the sediments (percent water), percent fixed and volatile solids, and the physical appearance and condition of the sediments before and after ashing. Results are summarized in tables 40 through 43.

The types of bottoms and the SOD rates varied within the lake system. A low SOD value of 3.73 grams per square meter per day (g/m^2/day) occurred in the open water area of Fox Lake. A high value of 31.58 g/m^2/day occurred in Pistakee Bay. The latter value exceeds by over threefold the highest value observed for the polluted bottoms of the upper Illinois Waterway (see table 42). The highest value found in a literature search is 19.2 g/m^2/day. Six of the 13 lake measurements exceeded the maximum recorded for the polluted sediments of the Illinois Waterway.

Generally, the bottoms of most of the lakes were composed of silts or marls, rich in organic materials. All were in a highly reduced state; all but one of the samples emitted noticeable hydrogen sulfide smells (table 43). Many samples showed a relatively high volatile solids content reflecting the organic content of the sediments. On the basis of the SOD results alone, it is concluded that most of the bottoms throughout the lake system are in some state of degradation.

The degree to which these bottoms affect the overlying water is primarily dependent upon water depth. For example, a bottom having a significant SOD in a deep stratified lake will quickly deplete the DO in the lower depths. The rate of oxygen demand cannot be maintained by natural reaeration or by photosynthesis. Oxygen used by high SODs in shallow waters is usually naturally replenished so that the influence of the degraded bottom conditions is not quite so evident as in deeper waters. As an example, Grass Lake which is relatively shallow in most areas (less than 5 feet), had extremely high SOD rates of 14.83 and 12.65 g/m^2/day in the two locations sampled. However, at the time of the SOD measurements the DO was above saturation even near the bottom. In contrast to this, the deep waters of Pistakee Bay and Lake Catherine were devoid of oxygen.

Even the lowest SOD recorded, 5.34 g/m^2/day for Fox Lake, is a highly significant SOD value and would cause rapid DO depletion in deeper lakes. Without oxygen replenishment an SOD rate of 3.73 g/m^2/day would deplete a 5-meter column of water saturated with dissolved oxygen at 20°C in approximately 12 days. For a severely degraded bottom such as that observed for Pistakee Bay, DO depletion would occur in less than 2 days. However, an inherent danger exists in having high SOD rates in shallow water. When the bottom sediments are resuspended physically, such as by boating activity, the SOD rate is momentarily increased several fold causing severe temporary oxygen depletion. As an example, the bottom of Grass Lake at station 14 remained disturbed for 20 minutes after lowering the sampler to the bottom; the disturbed SOD rate was 46.25 g/m^2/day compared with the stabilized rate

Table 40. Sediment Oxygen Demand Rates for Fox Chain of Lakes

Lake	*Temperature T (°C)*	*Time frame (min)*	*SOD at T°C*	*SOD at 25°C*
			(g/m^2/day)	
Catherine	13.8	0-2	91.63	153.27
		2-26	9.80	16.42
		24-53	7.76	_12.98_*
Marie (east)	20.8	0-4	26.18	32.04
		4-66	5.70	_6.91_*
Marie (west)	19.8	0-14	28.05	36.36
		14-49	12.72	_16.04_*
Bluff	20.25	0-26	9.82	12.13
		26-60	5.58	_6.98_*
Petite	20.3	0-10	13.75	16.98
		10-55	6.25	7.74
		55-103	5.59	_6.95_*
Fox	20.4	0-20	4.58	5.70
		20-62	2.81	_3.44_*
Stanton Bay (Fox Lake)	21.0	0-13	16.11	19.72
		13-64	5.78	_6.91_*
Mineola Bay (Fox Lake)	19.0	0-6	30.54	40.24
		6-60	4.12	_5.43_*
Nippersink	19.05	0-8	37.64	49.58
		8-68	6.33	_8.32_*
Pistakee	19.0	0-7	14.97	19.57
		7-55	4.36	_5.76_*
Pistakee Bay	20.5	0-2	144.00	177.06
		2-26	27.80	34.20
		26-41	42.76	52.58
		41-67	25.68	_31.57_*
Grass (south)	18.75	0-21	21.19	28.44
		21-61	11.13	_14.76_*
Grass (north)	17.9	0-20	33.38	47.11
		20-63	9.13	_12.54_*

*Italicized values represent stabilized linear portion of SOD curve

Table 41. Solid-Liquid Composition of SOD Samples

(Compositions in percent)

Lake	*Water*	*Fixed solids*	*Volatile solids*
Catherine	75.0	86.7	13.3
Marie (east)	40.0	90.7	9.4
Marie (west)	56.9	95.9	4.1
Bluff	25.5	74.4	25.6
Petite	17.5	85.3	14.7
Fox	62.2	90.8	9.2
Stanton Bay (Fox Lake)	52.3	92.8	7.2
Mineola Bay (Fox Lake)	80.4	74.2	25.8
Nippersink	79.2	79.4	20.6
Pistakee	73.8	83.3	16.7
Pistakee Bay	75.3	84.7	15.3
Grass (south)	55.8	96.7	3.3
Grass (north)	79.7	74.9	25.1
Cedar	23.7	84.2	15.8

Table 42. Comparison of SOD Values for Three Illinois Studies

Location	Number of samples	Range of values Water (%)	Volatile solids (%)	SOD at 25°C ($g/m^2/day$)
Illinois Waterway	22	33.0-74.9	2.5-25.7	0.64-9.30*
Lake Meredosia	3	66.3-69.4	8.8-8.9	2.83-4.74
Chain of Lakes	13	17.5-80.4	4.1-25.8	3.73-31.58

*Values from Butts (1974) revised

Table 43. Descriptions of Lake Bottoms at SOD Sampling Stations

Lake	Depth (ft)	Before incineration	After incineration
Catherine	39	Sulfide smell, thin watery gritty muck	Hard gray crust of silt and clay powderable
Marie (east)	10	Slight oily smell, muddy, gritty, slurry with fibrous material	Reddish-gray to brown with some very small shells, easily powdered
Marie (west)	10	Slight sulfide smell, small white snail shells and small-to-moderately large shell fragments, marl like	White snail shells and shell fragments, easily crushed to fine powder
Bluff	12	Sulfide smell, muddy, gritty, slurry	Clay-silt with some minute shell fragments, powderable
Petite	12	Strong sulfide smell, thin watery muddy grit	Gray hard crust, uniform silt-clay mixture
Fox	8	Slight sulfide smell, thin watery mud and small crushed shells	Very light fluffy mixture of snail and small clam shells, easily powdered
Fox (Stanton Bay)	4	Slight sulfide smell, muddy mixture of shells, fibers, and roots	Crusted mixture of calcium materials and shell fragments, easily powdered
Fox (Mineola Bay)	12	Sulfide smell, thin watery muddy grit	Moderately hard crust, light brown, powderable
Nippersink	6.5	Sulfide smell, thin watery muddy grit	Moderately hard crust light brown, powderable
Pistakee	5	Very strong sulfide smell, muddy, gritty slurry	Moderately hard crust light brown, powderable
Pistakee Bay	32	Sulfide smell, thin watery muddy grit	Moderately hard crust very light brown, powderable
Grass (south)	3.2	Slight sulfide smell, a little mud, mostly small white crushed shells	Dark snail shells and shell fragments, easily powdered
Grass (north)	3.2	Slight sulfide smell, thin watery grit	Soft reddish gray crust, easily powdered
Cedar	45	Sulfide smell, thin watery muddy grit	Fine reddish material with some leaf and wood ash, powderable

of 12.65 $g/m^2/day$. During this disturbed period the DO was lowered in the sampler by approximately 2.5 mg/l. In contrast, for a 43-minute period after restabilization occurred, the DO was lowered only 1.5 mg/l in the sampler. Table 40 lists the disturbed rates and the subsidence times for all the sampling locations. The consistency of the bottom sediments has a great influence on both the magnitude of the disturbed SOD rate and the time interval over which it is significant. SOD rates are highest in areas of algal silt type bottom sediment (figure 2).

Secchi Disc Observations

Secchi disc visibility is a measure of the lake water transparency or its ability to allow light transmission. Though the study of the light transmission by means of suitable photosensitive instruments lowered into the water has come into vogue, the very simple procedure of determining transparency, in a restricted sense, with the secchi disc still retains its value (Hutchinson, 1957).

Even though the secchi disc transparency is not an actual quantitative indication of light transmission, it serves as an index and a means of comparison of similar bodies of water or of the same body of water at different times. Since changes in water color and turbidity in a deep lake are generally caused by aquatic flora and fauna, transparency is often related to this entity. Greeson (1971) reported that in Oneida Lake in New York, the 1 percent penetration depth averaged 13.1 feet, and a concurrent secchi disc transparency reading averaged 5.6 feet which equaled the 10.5 percent penetration depth. The 1 percent penetration depth is generally defined as the lower limit of the euphotic zone.

The secchi disc observations in the lakes, and the maximum, minimum, and mean values, are shown in figure 97. The maximum of all the observations, 180 inches, was in Lake Catherine on June 3, 1975. However, Cedar Lake which is mesotrophic, exhibited the highest mean and highest minimum values. Among the Fox Chain of Lakes, Lake Catherine had the highest mean transparency value of 58 inches. The shallow lakes, namely, Fox, Nippersink, Pistakee, and Grass, showed an average value of about 10 inches.

Figure 97 reveals that the secchi disc values are somewhat related to the maximum depth in these lakes. This suggests that the boating activities and the wind and wave actions, which could stir up the bottom sediments in shallow lakes, affect significantly the depth of light penetration. Yousef (1974), assessing the effects of boating activities on water quality in shallow lakes of Florida, has documented that agitation and mixing caused by motorboats could increase the turbidity and average particle size of suspended material through the water column.

Turbidity

High turbidity affects the aesthetic quality of the water. Its origin may be municipal and industrial wastes, clastic materials derived from a drainage basin, soil erosion resulting from agricultural practices, urban and highway developments, sediments in lakes stirred by wind, wave, and high-speed boating activities in shallow lakes, detrital remains of aquatic and terrestrial plants and animals, and algae.

Lee (1974) suggests that if the turbidity in Green Bay (Lake Michigan) were reduced, more profuse algal growth might be encountered. Wang (1974) experimented with Illinois and Fox River waters to delineate the effects of turbidity on algal growth. He reported that unfiltered river water samples showed less algal growth than filtered samples under laboratory conditions. However, during periods of low nutrients in the water samples, unfiltered samples stimulated algal growth rather than retarded it. He concluded that the effect, inhibitory or stimulatory, may be related to the quantity of nutrients in solution.

Temporal variations of turbidity in three of the lakes investigated are shown in figures 98 through 104. These figures, in addition to turbidity, show the temporal variations of all of the chemical parameters evaluated. Figures 98, 99, and 100 pertain to Lake Catherine surface, mid-depth, and deep water samples, respectively. These are typical of the deep lakes in the Fox Chain. Figure 101 shows the temporal variations of the parameters in Fox Lake (main body) which is typical of the shallow lakes. Figures 102, 103, and 104 represent the water quality characteristics in the mesotrophic Cedar Lake. Table 44 summarizes the observed data for turbidity and the chemical parameters.

The turbidity of surface and mid-depth samples of deeper lakes had relatively low values ranging from 2 to 12 FTU. Turbidity in Cedar Lake was generally the lowest. This is mainly because the lake is entirely springfed and the horsepower of the motor boats used for recreational purposes is restricted to 5 hp. The deep water samples in the Chain of

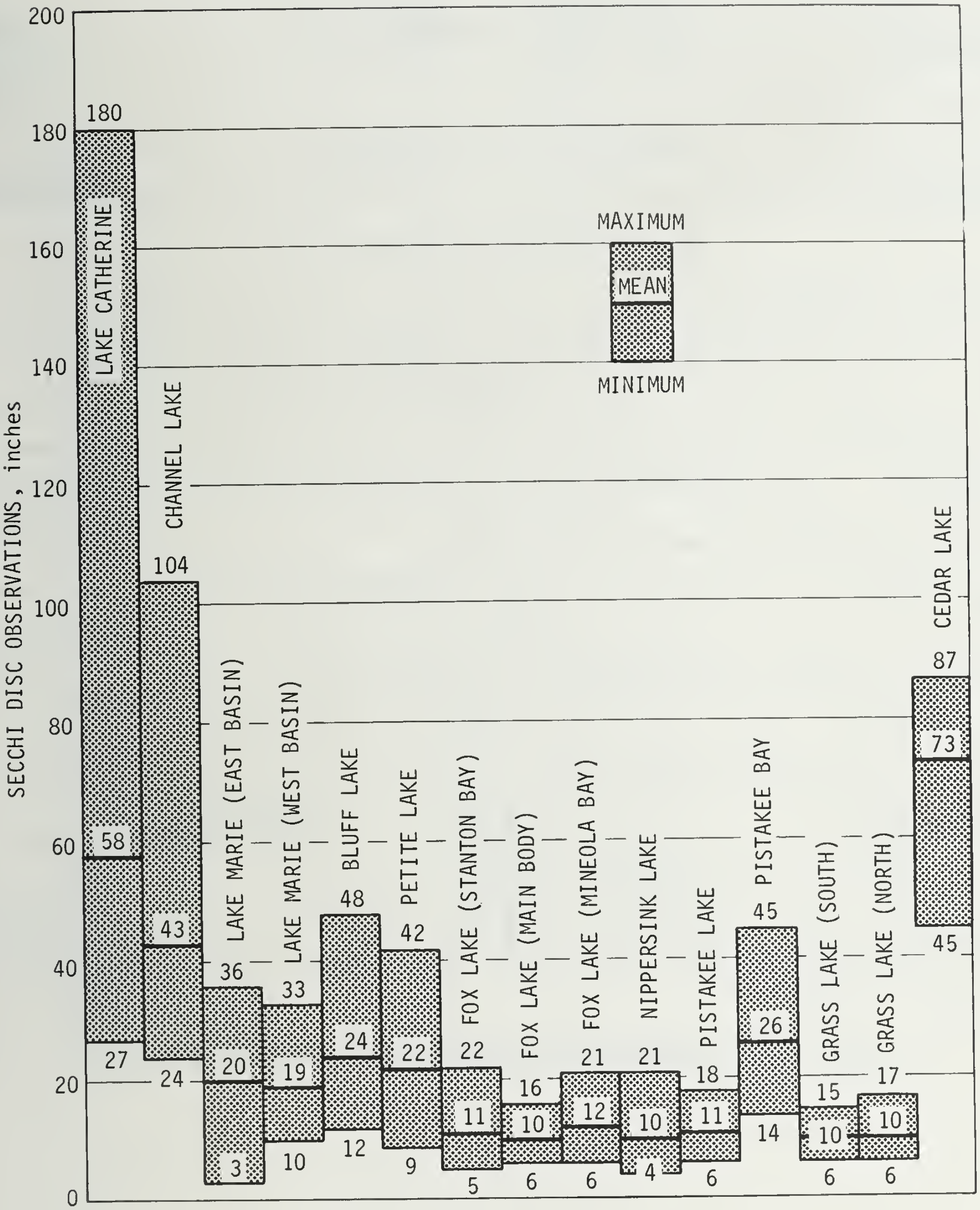

Figure 97. Secchi disc observations

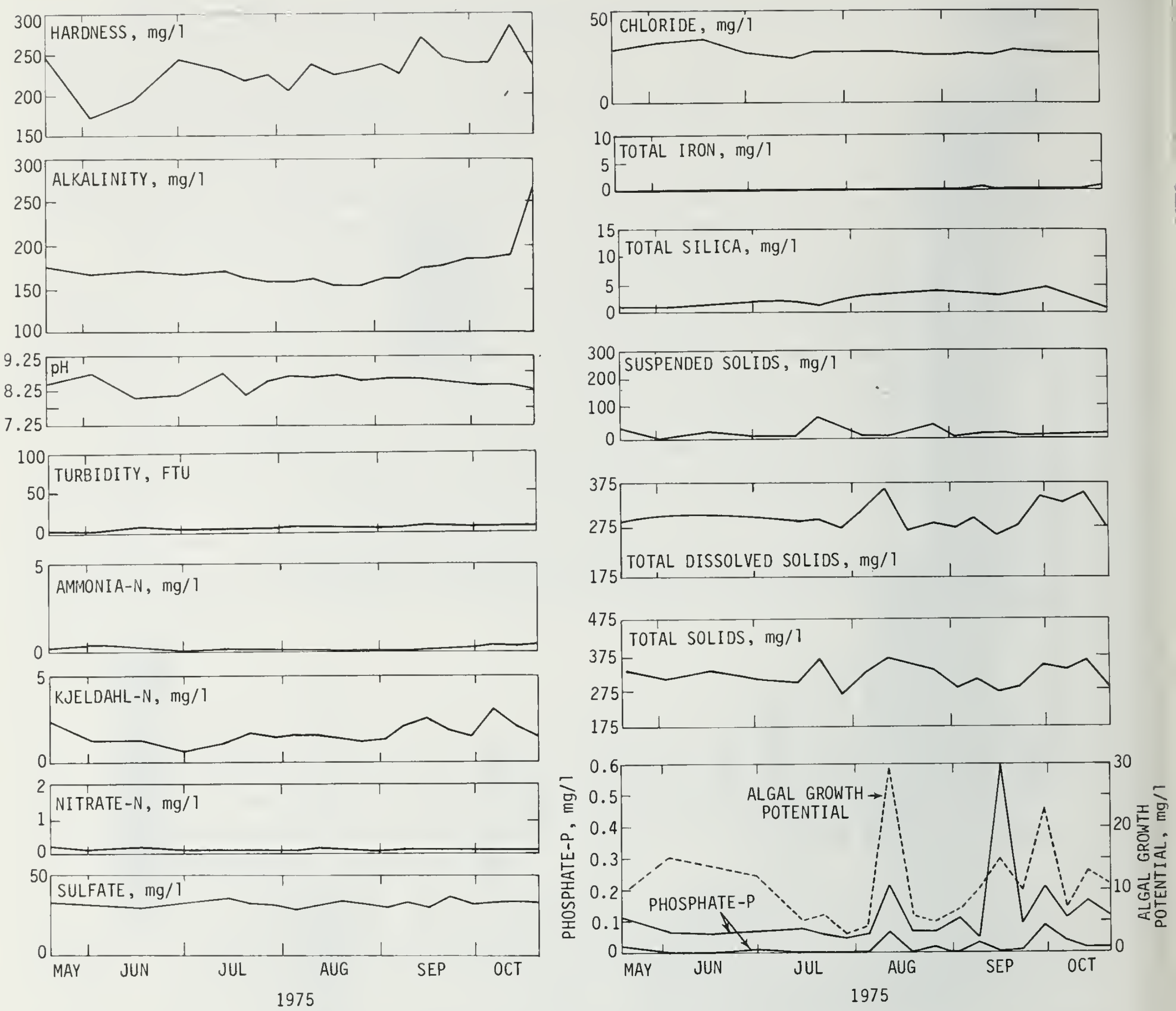

Figure 98. Temporal variations in water quality characteristics in Lake Catherine (surface)

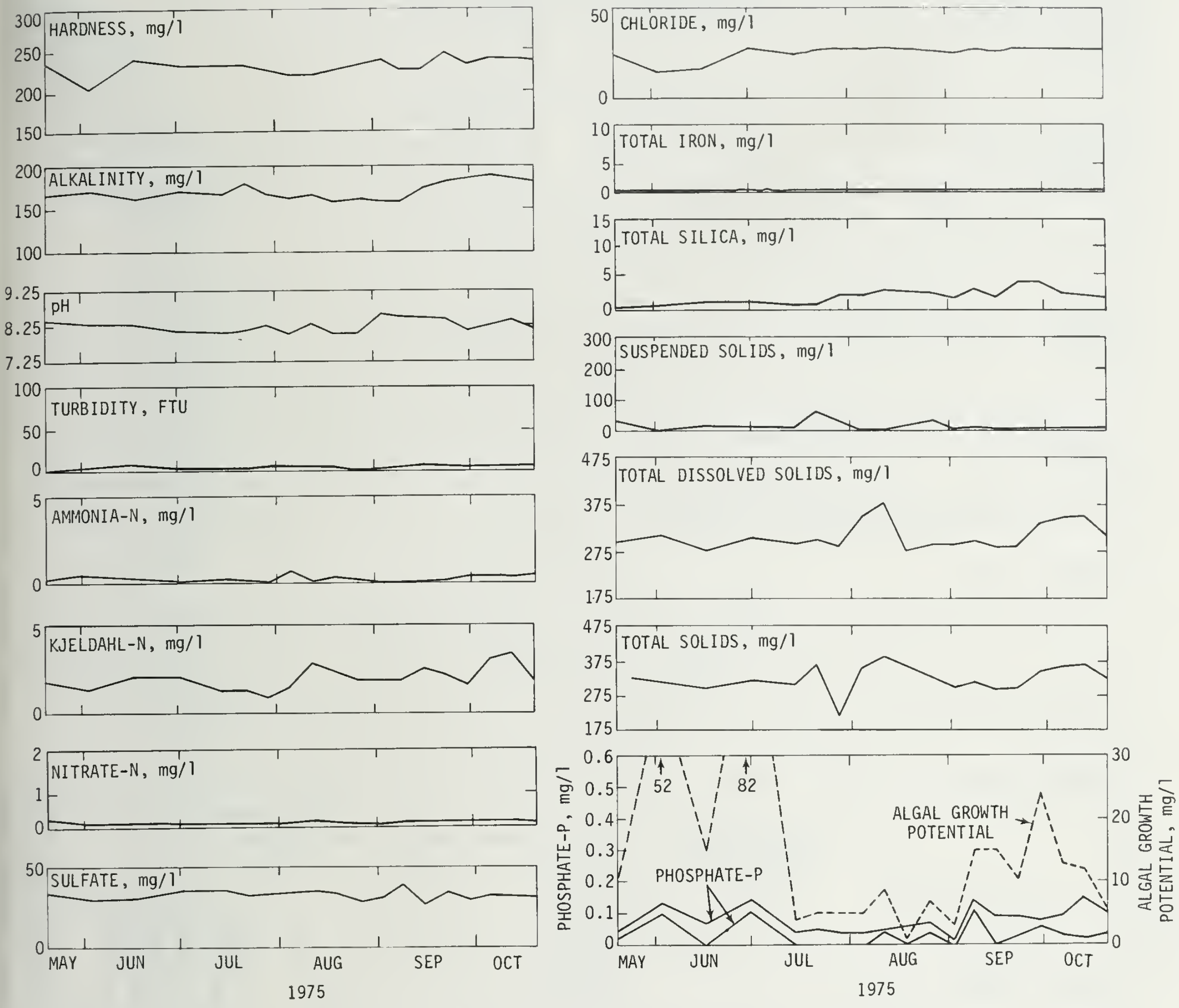

Figure 99. Temporal variations in water quality characteristics in Lake Catherine (mid-depth)

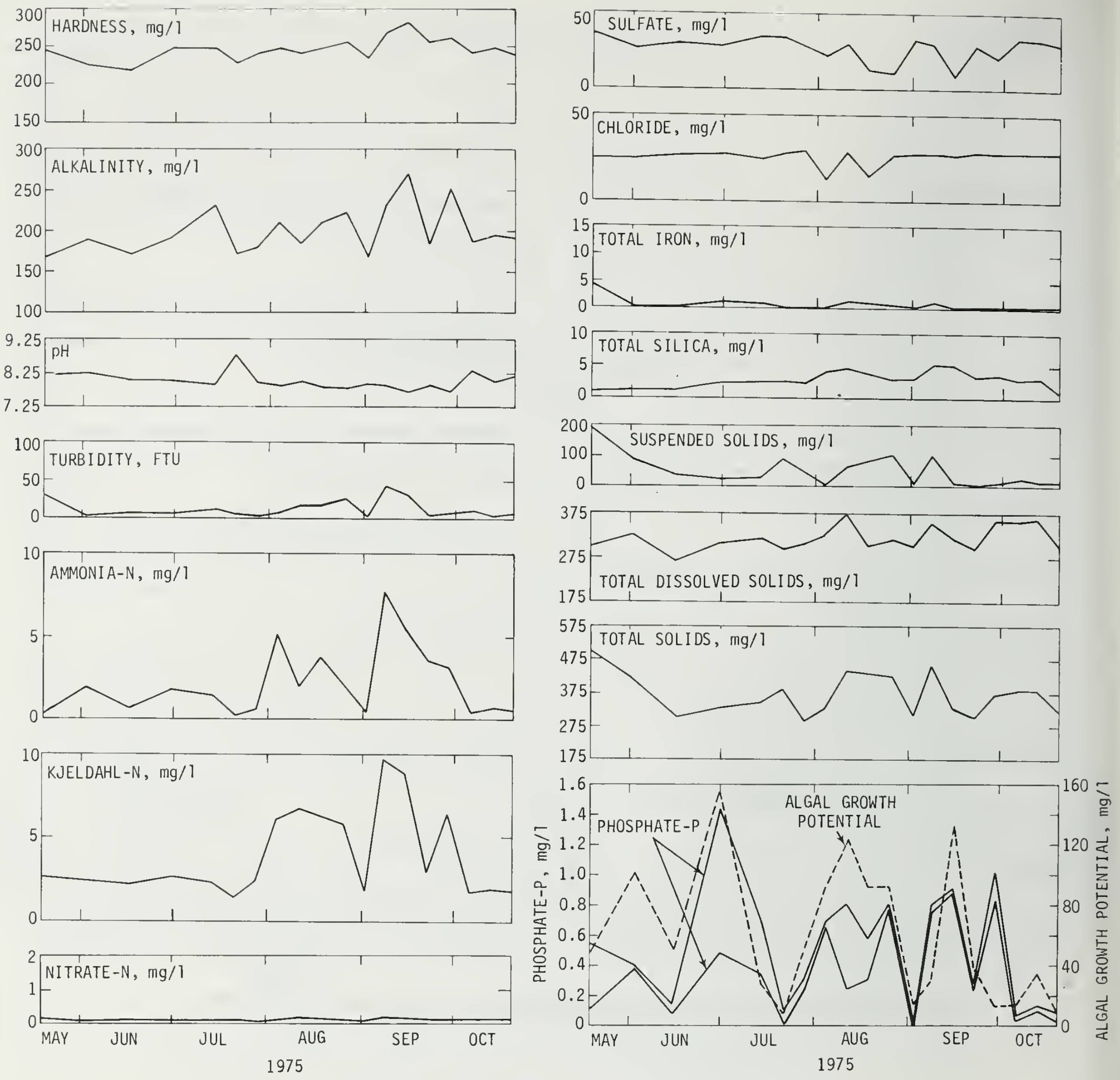

Figure 100. Temporal variations in water quality characteristics in Lake Catherine (deep)

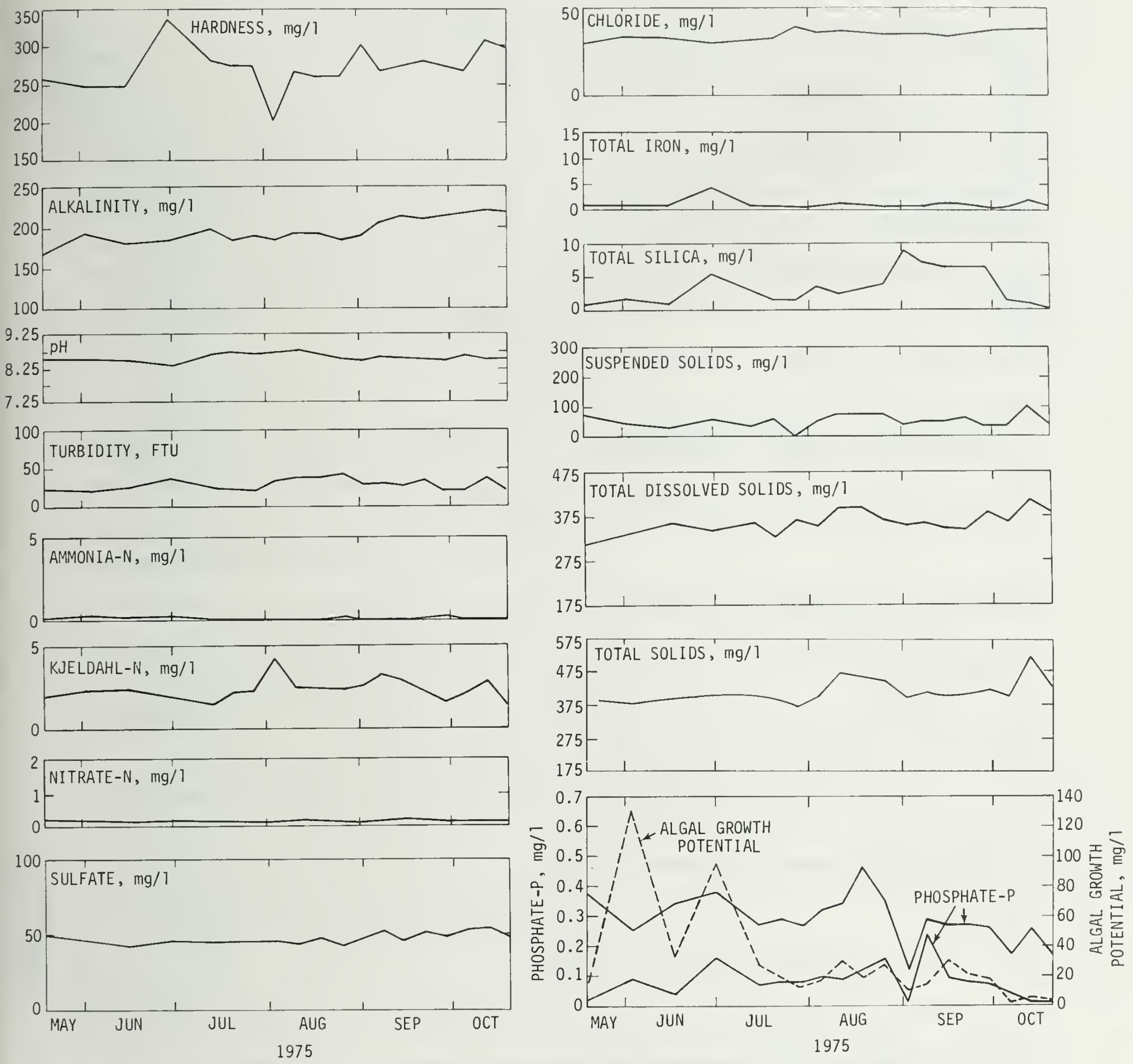

Figure 101. Temporal variations in water quality characteristics in Fox Lake (main body)

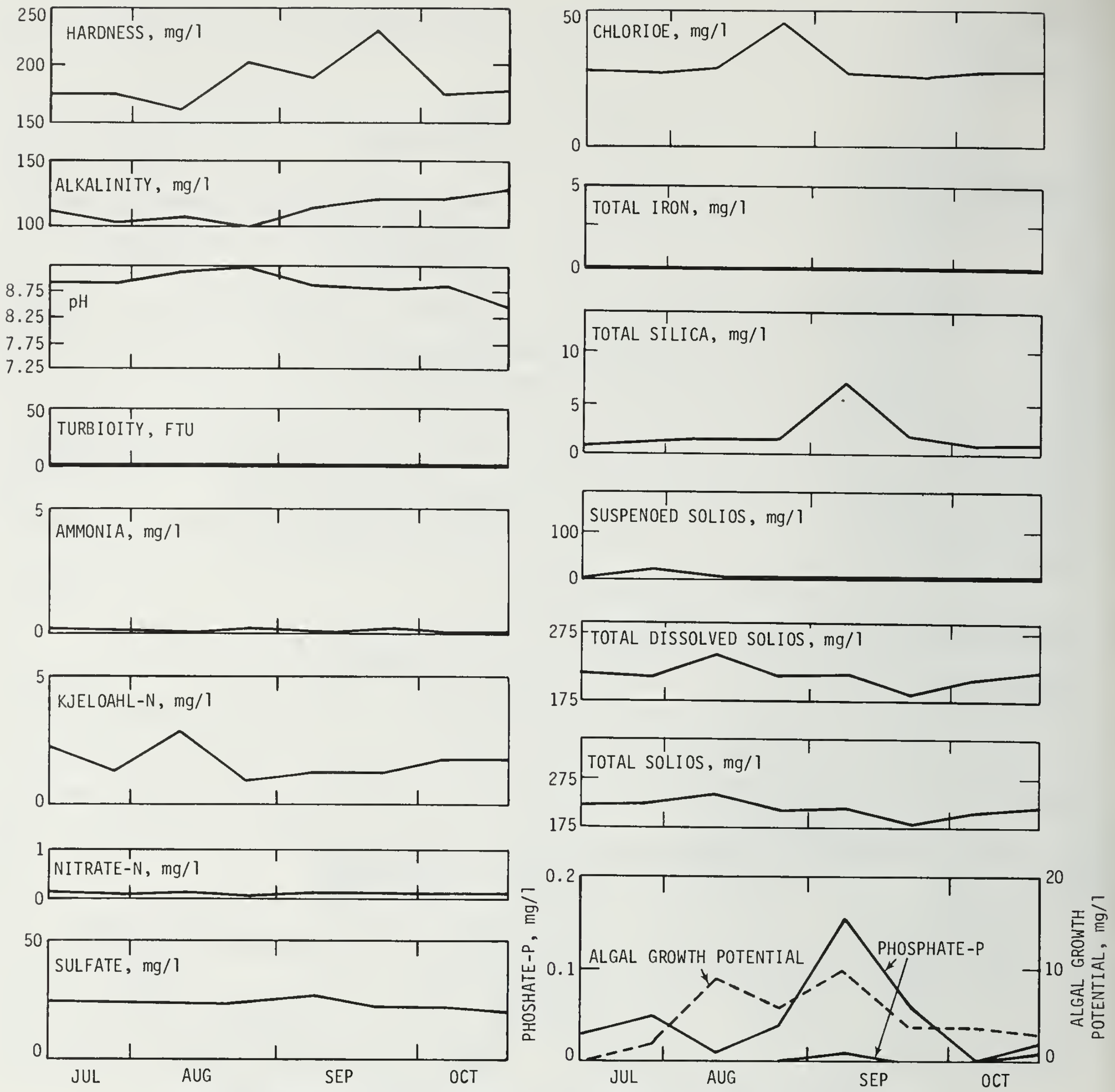

Figure 102. Temporal variations in water quality characteristics in Cedar Lake (surface)

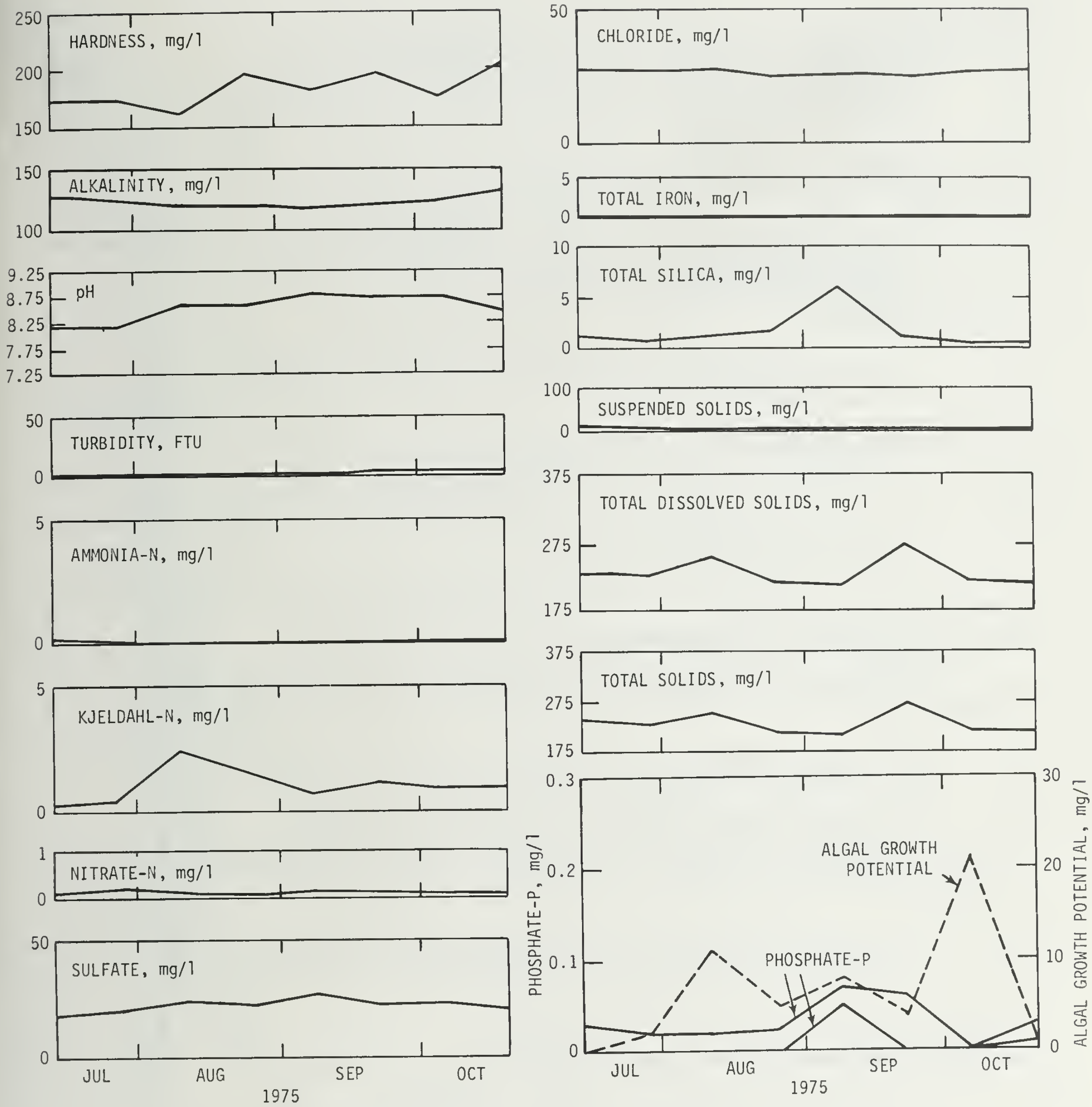

Figure 103. Temporal variations in water quality characteristics in Cedar Lake (mid-depth)

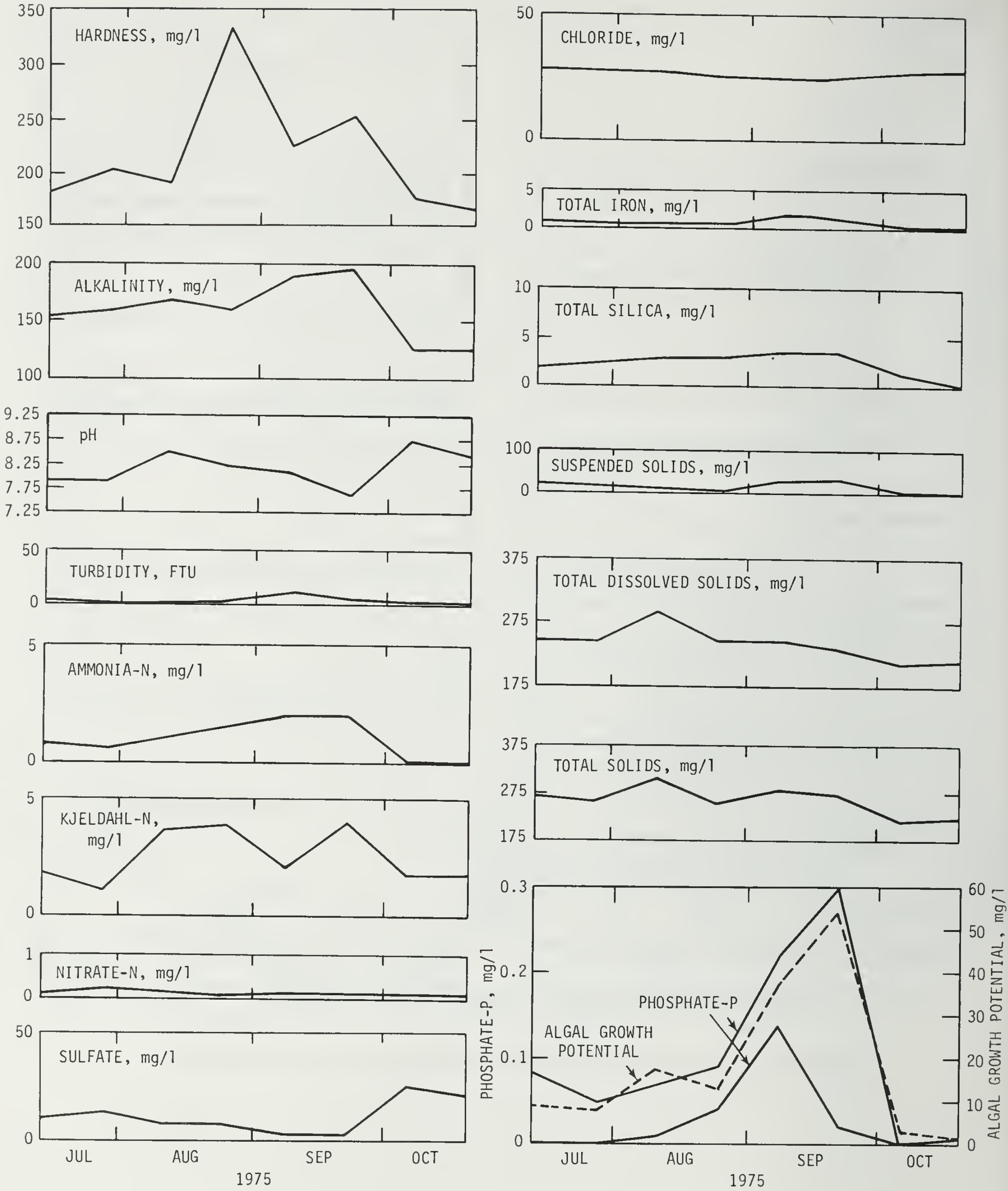

Figure 104. Temporal variations in water quality characteristics in Cedar Lake (deep)

Table 44. Summary of Water Quality Characteristics for Fox Chain of Lakes

(Concentrations in milligrams per liter)

Lake		*Depth at sampling point (ft)*	*Turbidity (FTU)*		*pH*	*Alkalinity*		*Hardness*		*Nitrate-N*		*Kjeldahl-N*	
			Mean	*Range*	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*
Catherine	Surface	39	5.4	2.2-7.7	8.01-8.72	176	155-270	231	170-285	0.13	0.07-0.26	1.62	0.61-2.97
	Mid-depth		4.3	1.4-7.2	8.04-8.59	173	160-192	228	200-244	0.13	0.06-0.25	1.91	0.85-3.37
	Deep		12.5	1.7-43.0	7.68-8.78	203	169-274	242	215-278	0.12	0.06-0.19	3.81	1.35-4.57
Channel	Surface	35	6.9	3.2-11.0	8.32-8.92	171	155-200	225	196-251	0.12	0.09-0.16	1.70	0.36-3.15
	Mid-depth		6.2	1.3-10.0	8.06-8.78	171	155-188	226	193-273	0.13	0.09-0.18	1.44	0.18-2.30
	Deep		14.0	2.1-77.0	7.58-8.80	200	164-278	240	185-285	0.13	0.07-0.19	4.21	0.90-13.10
Marie (east)	Surface	22	15.7	7.1-26.0	8.33-9.18	186	164-212	253	213-298	0.14	0.08-0.18	2.29	1.17-3.93
	Deep		17.7	6.8-52.0	8.20-8.92	187	160-212	259	226-278	0.14	0.08-0.19	2.43	1.05-4.25
Marie (west)	Surface	31	14.0	8.0-25.0	8.42-9.11	189	173-212	256	230-285	0.16	0.09-0.31	2.28	1.36-3.35
	Mid-depth		13.0	5.9-25.0	8.18-8.99	187	169-212	258	219-298	0.15	0.09-0.25	2.06	0.89-3.04
	Deep		21.9	3.6-72.0	7.68-8.78	207	155-271	266	200-291	0.15	0.08-0.23	4.13	1.18-12.50
Bluff	Surface	27	11.9	3.9-18.0	8.28-9.11	184	160-212	256	237-318	0.15	0.08-0.28	2.08	0.61-3.86
	Deep		19.3	3.5-84.0	7.45-8.80	215	173-275	267	207-305	0.14	0.09-0.22	5.31	1.31-12.90
Petite	Surface	17	14.5	6.4-31.0	7.97-9.18	186	160-216	253	222-305	0.15	0.10-0.23	2.49	1.14-4.21
	Deep		20.6	6.4-40.0	8.21-8.86	186	160-212	256	215-305	0.16	0.10-0.25	2.69	1.15-3.96
Fox (Stanton Bay)	Surface	4.4	29.0	11.0-63.0	8.30-8.91	194	160-223	271	222-332	0.17	0.11-0.25	2.46	1.03-5.84
Fox (main)	Surface	7.2	28.2	20.0-44.0	8.33-8.78	199	169-223	269	196-332	0.16	0.12-0.23	2.30	1.27-4.20
Fox (Mineola Bay)	Surface	12	22.7	16.0-50.0	8.44-8.91	196	173-227	272	196-325	0.17	0.12-0.29	2.55	1.45-4.08
	Deep		26.1	12.0-67.0	8.42-8.88	198	164-227	272	233-305	0.18	0.12-0.27	2.30	1.30-3.78
Nippersink	Surface	4.9	27.9	17.0-45.0	8.32-8.96	202	178-235	275	237-325	0.16	0.11-0.23	2.72	1.48-5.06
Pistakee (main)	Surface	5.4	23.5	15.0-32.0	8.32-8.88	211	182-255	288	244-330	0.26	0.11-0.47	2.52	1.26-3.55
Pistakee Bay	Surface	30	11.9	5.4-21.0	8.33-9.03	200	164-231	271	210-312	0.16	0.09-0.28	1.85	0.70-3.01
	Mid-depth		11.5	4.2-19.0	8.29-8.91	203	164-239	280	222-318	0.18	0.10-0.44	1.66	0.48-2.97
	Deep		22.1	2.7-82.0	7.54-8.62	235	178-320	290	219-393	0.16	0.08-0.23	4.75	0.97-15.50
Grass (south)	Surface	3.7	22.1	15.0-44.0	8.25-8.89	211	169-243	276	224-332	0.14	0.10-0.19	2.12	0.82-4.98
Grass (north)	Surface	3.3	20.7	10.0-38.0	8.36-8.96	207	164-235	278	237-305	0.15	0.10-0.24	2.49	1.28-3.91
Cedar	Surface	42	1.8	0.9-2.6	8.40-9.19	113	98-129	180	156-224	0.10	0.05-0.13	1.60	0.88-2.78
	Mid-depth		2.1	1.4-3.2	8.15-8.79	123	118-133	177	156-198	0.13	0.07-0.21	1.03	0.28-2.36
	Deep		4.1	1.4-12.0	7.57-8.69	160	125-196	209	158-325	0.12	0.07-0.21	2.46	0.96-3.81

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Table 44. (Continued)

(Concentrations in milligrams per liter)

Lake		*Depth at sampling point (ft)*	*Ammonia-N*		*Total silica*		*Total iron*		*Chloride*		*Sulfate*		*Total solids*	
			Mean	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*
Catherine	Surface	39	0.15	0.01-0.39	2.23	0.80-3.76	0.11	0.03-0.30	28	24-35	32	29-36	322	268-374
	Mid-depth		0.25	0.01-0.67	1.76	0.40-3.66	0.15	0.04-0.37	25	14-28	33	27-40	321	214-387
	Deep		2.12	0.20-7.50	2.61	0.62-4.71	0.54	0.05-4.03	25	12-29	26	8-36	367	290-502
Channel	Surface	35	0.09	0.00-0.24	2.59	0.00-5.74	0.21	0.04-1.56	26	23-29	33	27-36	327	280-371
	Mid-depth		0.15	0.02-0.74	3.13	0.00-11.92	0.15	0.01-0.57	27	23-29	34	28-40	335	284-535
	Deep		2.17	0.07-8.48	3.99	0.00-13.85	0.79	0.08-5.58	25	10-30	27	2-39	386	264-818
Marie (east)	Surface	22	0.09	0.00-0.59	2.65	0.00-5.63	0.33	0.10-0.65	33	25-37	44	36-50	377	317-458
	Deep		0.29	0.02-1.69	3.01	0.18-6.97	0.58	0.18-2.48	33	28-38	45	39-58	388	336-542
Marie (west)	Surface	31	0.11	0.01-0.35	2.47	0.07-5.90	0.31	0.11-0.75	34	30-38	45	36-52	374	316-419
	Mid-depth		0.18	0.01-0.58	2.40	0.0-6.76	0.37	0.19-0.74	34	29-38	44	34-50	377	324-420
	Deep		1.22	0.06-3.85	3.43	0.18-7.40	1.00	0.15-3.75	34	29-38	38	13-51	420	342-576
Bluff	Surface	27	0.12	0.01-0.37	2.83	0.00-8.25	0.24	0.04-0.46	34	29-40	45	36-79	369	330-434
	Deep		2.76	0.05-9.15	3.76	0.04-7.20	0.90	0.06-4.92	31	14-37	36	7-56	404	324-650
Petite	Surface	17	0.09	0.00-0.56	3.57	0.00-6.64	0.29	0.10-0.59	33	24-38	43	35-52	367	324-418
	Deep		0.21	0.01-0.91	3.60	0.18-6.04	0.75	0.15-2.06	33	29-38	45	36-51	394	336-489
Fox (Stanton Bay)	Surface	4.4	0.10	0.00-0.30	3.76	0.00-9.24	1.01	0.17-5.88	34	30-39	46	40-55	417	367-478
Fox (main)	Surface	7.2	0.12	0.02-0.33	3.48	0.00-8.67	0.95	0.31-4.01	35	30-39	48	42-55	415	372-519
Fox (Mineola Bay)	Surface	12	0.10	0.00-0.27	3.86	0.08-10.55	0.58	0.16-1.36	34	28-42	49	44-59	398	374-433
	Deep		0.19	0.02-0.67	4.14	0.08-8.72	0.85	0.27-2.34	35	28-41	48	43-55	427	366-544
Nippersink	Surface	4.9	0.06	0.00-0.14	3.27	0.28-7.38	1.19	0.56-2.79	35	29-42	50	41-58	421	354-488
Pistakee (main)	Surface	5.4	0.10	0.01-0.27	3.66	0.00-9.66	1.11	0.39-3.17	34	29-38	49	40-56	426	376-504
Pistakee Bay	Surface	30	0.11	0.00-0.53	2.22	0.00-6.60	0.23	0.07-0.60	33	28-38	47	40-56	385	346-436
	Mid-depth		0.19	0.03-0.68	2.91	0.25-6.61	0.28	0.11-0.66	32	26-38	48	41-56	390	334-474
	Deep		3.55	0.05-16.38	4.98	0.18-9.31	0.77	0.14-3.36	31	14-39	38	8-54	423	328-624
Grass (south)	Surface	3.7	0.08	0.00-0.16	1.96	0.32-6.30	1.72	0.32-5.38	37	30-45	49	36-55	441	326-778
Grass (north)	Surface	3.3	0.05	0.00-0.11	1.11	0.00-3.12	1.17	0.30-3.14	35	33-44	49	33-64	418	350-526
Cedar	Surface	42	0.08	0.02-0.14	1.90	0.81-6.65	0.07	0.00-0.15	29	25-45	23	20-27	216	185-243
	Mid-depth		0.06	0.02-0.11	1.62	0.43-5.88	0.06	0.00-0.09	27	25-28	22	18-27	232	210-272
	Deep		0.96	0.01-1.94	2.59	0.00-3.47	0.60	0.06-1.70	26	24-28	11	2-24	257	212-303

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Table 44. (Concluded)

(Concentrations in milligrams per liter)

Lake		*Depth at sampling point (ft)*	*Dissolved solids*		*Suspended solids*		*AGP*		*Total phosphorus*		*Dissolved orthophosphorus*	
			Mean	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*
Catherine	Surface	39	307	264-370	16	0-70	10	3-23	0.12	0.05-0.60	0.03	0.00-0.09
	Mid-depth		311	278-384	14	0-62	15	1-82	0.08	0.01-0.15	0.05	0.00-0.11
	Deep		322	268-376	47	1-202	59	7-147	0.51	0.01-1.44	0.39	0.00-0.90
Channel	Surface	35	308	270-358	20	0-80	10	1-23	0.12	0.05-0.30	0.04	0.00-0.15
	Mid-depth		316	264-526	20	0-62	14	1-56	0.10	0.01-0.26	0.03	0.00-0.12
	Deep		318	276-380	77	0-448	67	5-180	0.50	0.05-1.63	0.42	0.00-1.24
Marie (east)	Surface	22	343	300-396	37	0-158	27	5-103	0.23	0.09-0.43	0.07	0.00-0.19
	Deep		349	304-396	43	2-162	33	7-145	0.27	0.05-0.83	0.12	0.01-0.68
Marie (west)	Surface	31	346	302-394	33	0-96	22	3-71	0.20	0.08-0.33	0.07	0.00-0.23
	Mid-depth		351	314-392	29	4-78	27	1-101	0.22	0.09-0.37	0.08	0.00-0.19
	Deep		361	318-408	66	6-246	62	3-173	0.63	0.14-1.78	0.50	0.00-1.74
Bluff	Surface	27	346	306-416	25	2-74	23	8-64	0.21	0.06-0.52	0.08	0.00-0.19
	Deep		352	306-404	57	6-320	76	2-182	0.81	0.11-1.90	0.65	0.00-1.81
Petite	Surface	17	344	302-384	25	0-49	24	1-92	0.22	0.10-0.32	0.07	0.00-0.16
	Deep		344	294-396	52	2-148	28	4-137	0.28	0.15-0.50	0.11	0.00-0.32
Fox (Stanton Bay)	Surface	4.4	361	322-398	55	14-124	20	1-72	0.25	0.07-0.39	0.06	0.00-0.11
Fox (main)	Surface	7.2	364	316-414	53	2-105	28	2-129	0.28	0.12-0.38	0.08	0.01-0.24
Fox (Mineola Bay)	Surface	12	359	316-400	39	12-82	29	3-95	0.27	0.14-0.41	0.09	0.01-0.14
	Deep		361	320-410	69	20-184	30	10-101	0.28	0.10-0.46	0.10	0.01-0.18
Nippersink	Surface	4.9	363	338-408	60	33-134	21	2-55	0.30	0.16-0.41	0.06	0.00-0.12
Pistakee (main)	Surface	5.4	368	324-408	56	15-138	23	9-57	0.27	0.12-0.40	0.06	0.00-24.00
Pistakee Bay	Surface	30	362	324-418	24	8-104	30	5-203	0.17	0.08-0.25	0.06	0.00-0.13
	Mid-depth		363	280-436	29	0-124	26	10-100	0.18	0.09-0.27	0.07	0.00-0.16
	Deep		372	252-484	57	4-254	80	8-216	0.87	0.08-2.61	0.73	0.00-2.47
Grass (south)	Surface	3.7	366	315-422	80	0-432	15	3-28	0.33	0.10-0.63	0.03	0.00-0.10
Grass (north)	Surface	3.3	360	316-402	64	22-148	17	1-64	0.27	0.14-0.39	0.03	0.00-0.06
Cedar	Surface	42	212	184-242	4	1-16	5	0-10	0.05	0.00-0.13	0.00	0.00-0.01
	Mid-depth		229	210-272	3	0-12	7	0-21	0.04	0.00-0.07	0.01	0.00-0.05
	Deep		242	210-294	15	2-34	17	1-54	0.12	0.00-0.30	0.03	0.00-0.14

Lakes exhibited high turbidity. It was most likely due to the active decomposition of the bottom sediments. The turbidity of deep water samples in Cedar Lake was relatively low, because of the low productivity of that lake.

The surface turbidities in the shallow lakes, Fox, Nippersink, Pistakee, and Grass, were much higher than surface turbidities of deeper lakes. This must be primarily due to the resuspension of bottom sediments in the shallow lakes. Grass Lake, throughout the period of this investigation, exhibited a brownish color akin to soil and humus. The other shallow lakes reflected a greenish hue during periods of algal bloom.

Chemical Characteristics

pH

It is generally considered that pH values above 8.0 in natural waters are produced by a photosynthetic rate that demands more carbon dioxide than the quantities furnished by respiration and decomposition (Mackenthum, 1969). Values of pH below 8.0 indicate failure of photosynthesis to utilize completely the carbon dioxide so produced. Photosynthesis by aquatic plants utilizes carbon dioxide, removing it from bicarbonate and producing carbonate, when no free carbon dioxide exists in the water medium. Carbonates of calcium and magnesium, which are weakly soluble tend to precipitate out. Decomposition and respiration tend to reduce pH and increase bicarbonates, whereas the tendency of photosynthesis is to raise pH and reduce bicarbonates.

As seen from figures 98, 101, and 102 and table 44, the pH values of lake surface water samples were never less than 8.0 and they generally fluctuated, with very few exceptions, in the range of 8.0 to 9.0. This is indicative of active photosynthesis in which carbon dioxide is utilized from the bicarbonate alkalinity. Bottom sediments mixed with marl, of biological origin, were found extensively in the lake system.

During the periods of thermal stagnation in the deep lakes, deep water samples had pH values less than 8.0 generally when the bottom sediments were undergoing anaerobic decomposition (figures 100 and 104). The pH values of these waters appear to increase when the lakes experience fall overturn.

Alkalinity and Hardness

These factors are governed to a large extent by the geochemistry of the watershed of the lakes. The lakes of the Fox Chain are typical of Midwestern lakes, high in alkalinity and hardness. The interrelationship of alkalinity, pH, photosynthesis, and to a certain extent of hardness, was discussed in an earlier section, *"Water Quality of the Lakes and Streams."*

Alkalinity of the surface water samples in the Fox Chain of Lakes ranged from a low of 155 mg/l to a high of 278 mg/l. The mean alkalinity values for surface samples exhibit a spatial variation among the lakes. In the upper lakes of the Chain (Catherine, Channel, Marie, Bluff, and Petite), which are deeper than the rest, the mean alkalinity values are lower. Also in these lakes, the alkalinity in deep water samples are relatively higher than their corresponding surface sample values. This is true also in the case of Cedar Lake, which most of the time had the lowest of all the observed values. Differences between summer and winter alkalinity values have been used to define the trophic status of lakes in Europe (Vollenweider, 1968), oligotrophic lakes showing the least change. The temporal variations of alkalinity in the surface samples were moderate. Deep water sample variations, however, showed a noticeable peak-and-valley pattern.

The mean hardness values of surface water samples of the deep upper lakes are lower than those of the shallower lakes in the Chain. However, the differences between the surface, mid-depth, and deep values are insignificant. The hardness of Cedar Lake waters is considerably less than that of the lakes of the Fox Chain. Fluctuations of hardness values with time are much more pronounced when compared with the variations in alkalinity.

Nitrogen

Nitrogen is present in water either as dissolved organic nitrogen, or as inorganic nitrogen such as ammonium, nitrate or nitrite, or as elemental nitrogen. These various forms cannot be used to the same extent by different groups of aquatic plants and algae. Nitrogen is one of the principal elemental constituents of amino acids, peptides, proteins, urea, and other organic matters.

Vollenweider (1968) reports that in laboratory tests, the two inorganic forms of ammonia and nitrate are as a general rule used by planktonic algae to roughly the same extent. However, Wang et al. (1973) reported that during periods of maximum algal growth under laboratory conditions ammonium nitrogen was the source of nitrogen preferred by planktons. In the case of higher initial concentrations of ammonium salts, yields were noted to be lower than equivalent concentrations of nitrates (Vollenweider, 1968). This was attributed to the toxic effects of ammonium salts. The use of nitrogenous organic compounds has been noted by several investigators according to Hutchinson (1957). However, Vollenweider (1968) cautions that the direct use of organic nitrogen by planktons has not been definitely established, citing that not one of 12 amino acids tested with green algae and diatoms was a source of N when bacteria free cultures were used. But the amino acids were completely used up after a few days when the cultures were inoculated with a mixture of bacteria isolated from water. He has opined that in view of the fact that there is always bacterial fauna active in nature, the question of the use of organic nitrogen sources is of more interest to physiology than to ecology.

The mean nitrate concentrations in all the lakes, including Cedar Lake, and at all the depths examined were similar. The temporal variations were also moderate. With one or two exceptions the ranges of values for nitrate observed in all the lakes were comparable.

Kjeldahl nitrogen, as reported here, is the combination of ammonia nitrogen and organic nitrogen in the water samples. In the case of deep lakes, the Kjeldahl nitrogen concentrations at surface and mid-depth were comparable to those of shallow lake surface water samples. However, the concentrations in deep water samples were nearly two to three times those observed for the surface. Increase in ammonia concentrations in the deep water zones, because of anaerobic decomposition of settled organic matter, accounts for most of the increase in the Kjeldahl nitrogen concentrations reported here. The temporal variations of ammonia and Kjeldahl nitrogen shown in figures 98 through 104 indicate that these values are much higher in deeper zones of the lake. The ammonia and organic nitrogen concentrations in deep water samples increased during the period of lake stagnation but dropped significantly as soon as the fall overturn occurred. The values of ammonia and Kjeldahl nitrogen in the surface samples of Cedar Lake are comparable to those of the deep lakes, namely, Catherine, Channel, and Marie, and Pistakee Bay. However, the values for the deep water samples in Cedar Lake are significantly less when compared with the values for the deep lakes of the Chain. This is probably indicative of the extent of organic silt accumulation and subsequent decomposition in these lakes.

Silica

The element silicon is not found free in nature, but it occurs as silica (silicon dioxide) in the form of finely divided or colloidal matter. An abundance of silica in water, along with other necessary nutrients, favors the growth of diatoms. Lee (1974) postulates that when phosphate detergents are replaced by silicate based detergents, the silica budget for Lake Michigan could increase. This could result in reversing the current trend of the change from diatoms to green and blue-green algae associated with increasing phosphorus input. Since diatoms contain significant amounts of silica in the frustule, they can be expected to alter the silica concentrations in water bodies. Wang and Evans (1969) reported a high degree of inverse relationship between silica and diatom populations which constitute 60 to 90 percent of algal counts in the Illinois River.

The shallow lakes with the exception of Grass Lake showed higher silica concentrations than did the deeper lakes. The higher concentrations are probably associated with higher suspended solids and turbidity in these lakes. A high degree of association among these parameters has been reported in the past. The predominant algal species in Grass Lake were diatoms, constituting about 75 percent of the algal population. This could account for the lower values for silica in Grass Lake compared with the other shallow lakes in the system. The temporal variations of silica for deep waters, shown in figures 98 and 104 suggest that this nutrient is released from the mud-water interface to the overlying waters during the periods of lake stagnation.

Iron

Iron in amounts occurring in natural waters is not detrimental to biological life processes. Limits on iron concentrations are not based upon physiological considerations but rather on aesthetic and taste considerations. Iron in trace amounts is essential for nutrition. Certain bacteria, Crenothrix and Gallionella, and other iron bacteria utilize iron as a source of energy and store it in their protoplasm. The relatively insoluble ferric compounds associated with lake sediments are reduced to more readily soluble ferrous compounds under anaerobic conditions and released to the overlying waters.

The observations made for silica in the lakes also appear to hold true for iron. The surface sample iron concentrations in deep lakes are much lower than those in the shallow lakes. The higher concentration of iron in shallow lakes is probably associated with increased turbidity and suspended matter. Concentrations in Grass Lake are also high and comparable to other shallow lakes. Iron concentrations are significantly higher in the deep waters of the lakes. The mean and range of values observed for iron in the lakes are shown in table 44. The temporal variations in iron for three of the lakes investigated are shown in figures 98 through 104.

Chloride

Chlorides are found in practically all natural waters. They may be of mineral origin, or derived from human and animal wastes, industrial effluents, road salting during winter, or other sources. Chloride is a conservative element and is not directly involved in any of the physical or biological processes occurring in natural water bodies.

The mean and range of values for chloride are shown in table 44. Except for a few abrupt fluctuations in chloride values, temporal variations appear to be insignificant (figures 98 through 104). The chloride values observed in the Fox Chain of Lakes are comparable to the values found in Lake Evergreen (Kothandaraman and Evans, 1975) and in Lake Bloomington.

Sulfate

Sulfates occur naturally in water as a result of leaching gypsum, pyrite bearing strata, and other common minerals. Sulfates may also occur as the oxidized state of organic matter in the sulfur cycle, but they, in turn, may serve as an energy source for sulfur bacteria. Experiments indicate that waters containing less than 0.5 mg/l of sulfate will not support growth of algae (McKee and Wolf, 1963). Apart from the fact that sulfate exerts a cathartic effect on transient users, recommended limits on sulfate do not appear to be based on taste or physiological effects.

With the exception of Lake Catherine and Channel Lake, the mean sulfate concentrations of surface and mid-depth water samples are comparable and fall within the narrow range of 43 to 50 mg/l. Sulfate concentrations in these two lakes are much lower. Cedar Lake exhibited the lowest of all values observed. Sulfate concentrations in the deep water zones were much lower than in the surface or mid-depth water samples because of the anaerobic reduction of sulfate to hydrogen sulfide as evidenced by the strong septic odor noted during the sampling of the deep water zones. The temporal variations of sulfate, as shown in figures 98 through 104, are relatively small in surface and mid-depth waters. There is a reduction and greater fluctuation of sulfate in the deep waters.

Total Solids, Total Dissolved Solids, and Suspended Solids

Total solids, as presented here, include total dissolved solids and suspended solids. In natural waters, the dissolved solids consist mainly of carbonates, bicarbonates, sulfates, chlorides, phosphates and nitrates of calcium, magnesium, sodium, and potassium with traces of iron, manganese, and other substances. The constituent composition of these minerals are to a large extent dependent on the geochemistry of the area contributing to the surface or groundwater resource. The amount of suspended solids found in impounded waters is small compared with the amount found in streams because solids tend to settle to the bottom in lakes. However, this aspect is greatly modified in shallow lakes by wind and wave actions and by the type and intensity of use to which these lakes are subjected.

All salts in solution change the physical and chemical nature of the water and exert an osmotic pressure. Some have physiological as well as toxic effects. However, possible synergistic or antagonistic interreactions between mixed salts in solution may cause the effects of salts in combination to be different from those of salts occurring separately.

Greeson (1971) observed that high dissolved solids contents of Oneida Lake (New York) in 1967 and 1969 accompanied the high production of algae. Low dissolved solids content in 1968 accompanied lesser algal production. He concluded that these relationships indicate that the dissolved solids content is an important index of potential productivity conditions because no element, ion, or compound is likely to be a limiting factor on algal production when the dissolved solids content is high.

All of the lakes in the Fox Chain except Catherine and Channel exhibited similar values of solids concentrations. Catherine and Channel exhibited values next in order of magnitude. Cedar Lake had the lowest solids concentrations of all. The total dissolved solids and suspended solids concentrations in deep waters were relatively higher than the respective values for mid-depth and surface water samples. This is essentially due to the solubilization and release to overlying waters of settled decomposing organic matter. The increased suspended matter in the deep water samples is most likely caused by the dislodging of the sediments by the evolving gaseous by-products of anaerobic decomposition. The temporal variations of suspended, total dissolved, and total solids shown in figures 98 through 104 are typical of all the lakes investigated.

Algal Growth Potential (AGP) and Phosphorus

Because of the strong association of phosphorus and algal growth potential observed in this investigation, these two parameters are treated together. Moreover, phosphorus has been implicated as being primarily responsible for algal blooms in lakes. Gakstatter et al. (1975) reported that out of 623 lakes surveyed in the states east of the Rocky Mountains, under the National Eutrophication Survey Program, 67 percent were phosphorus limited.

Algal growth potential (AGP), as previously discussed, is a laboratory procedure carried out under standard and controlled conditions to determine the extent of algal growth sustained by the filtered water sample after being inoculated with a mixed algal culture obtained from a surface water source. Though it is impossible to duplicate in the laboratory all the conditions obtainable in nature, this test provides at least a relative estimate of the algal growth potentials of a water body over a period of time or between different bodies of water.

Phosphorus is an active element which does not occur free in nature. It is found in the form of phosphates in several minerals and it is a constituent of fertile soils, plants, protoplasm, and tissues and bones of animal life. It is an essential nutrient for plant and animal growth, and like nitrogen, it passes through cycles of photosynthesis and decomposition. Phosphorus plays a vital role in the energy transfers during cell metabolism. The most important form of phosphorus for plant nutrition is ionized phosphate.

The phosphorus compounds present in water are generally classified as orthophosphorus, polyphosphates, and organic phosphorus of both dissolved and particulate forms (Sullivan and Hullinger, 1969; Vollenweider, 1968). Only total phosphorus and dissolved orthophosphorus, which is the most readily available form for plant growth, were considered in this investigation.

Sawyer (1952), from his experimental work with Wisconsin lakes, concluded that aquatic blooms are likely to develop in lakes during summer months when concentrations of inorganic nitrogen and inorganic phosphorus are in excess of 0.3 mg/l and 0.01 mg/l, respectively. These critical levels for nitrogen and phosphorus concentrations have been accepted and widely quoted in scientific literature. Numerous published reports indicate that productivity is largely determined by two factors, i.e., phosphorus and nitrogen. Phosphorus is predominant over nitrogen as a limiting factor. Vollenweider (1968) concluded, after extensive analyses of data pertaining to the lakes of central Europe, that the critical levels for phosphorus and nitrogen concentrations suggested by Sawyer were also valid for those lakes. He further observed that phosphorus was the more critical of the two nutrients.

The mean and range of values for phosphorus concentrations and AGP in the Fox Chain of Lakes and Cedar Lake are shown in table 44. Temporal variations in these parameters for three of the Chain lakes typical of deep, shallow, and nutrient deficient lakes are shown in figures 98 through 104. From the data presented, it is seen that the mean dissolved orthophosphorus concentrations in Cedar Lake are much less than the values observed in the Fox Chain of Lakes. Characteristically, the dissolved orthophosphorus concentrations in the deep water zones were found to be several orders of magnitude higher than the values determined for surface and mid-depth water samples in these lakes. This was true in the case of Cedar Lake also. However, a comparison of the mean dissolved orthophosphorus concentrations in the deep water samples indicates that concentrations in the Fox Chain of Lakes are 10 to 25 times the value observed for Cedar Lake. The mean orthophosphorus concentrations in the surface and mid-depth samples were 0.00 and 0.01 mg/l, respectively.

The orthophosphorus concentrations in the surface and mid-depth samples in the Chain lakes were higher than the critical levels of phosphorus concentration suggested by Sawyer (1952). The mean orthophosphorus concentrations observed in deep zones of the Fox Lakes were about 40 to 75 times higher than the critical level.

The temporal variations in phosphorus concentrations and the AGP values shown in figures 98 through 104 suggest a strong association between the AGP of the lake water samples and the phosphorus concentrations. The AGP values for Cedar Lake were very low, and the lake showed the lowest algal densities of all the lakes investigated. The AGP values determined with deep water samples from the Chain lakes showed consistently high values. The phosphorus concentrations in these samples were very high compared with surface and mid-depth sample values.

Considering the phosphorus concentrations, AGP values, and the algal densities observed in the Fox Chain of Lakes and Cedar Lake, it can be concluded that phosphorus is the key element in the eutrophic condition of the Fox lakes. The nitrate-nitrogen concentrations in all the lakes including the deep water zones were comparable. Ammonia concentrations were higher in the hypolimnetic zones of the deep lakes. Phosphorus appears to be the most critical of the two nutrients.

Biological Characteristics – Phytoplankton

The frequency and locations for phytoplankton collections were the same as those previously described for chemical analyses. In the deeper bodies of water (Lake Catherine, Channel Lake, Lake Marie (west), Pistakee Bay, and Cedar Lake) samples were collected at the surface, mid-depth, and about 1 foot from the bottom. At the other 10 locations (see table 45) samples were collected at the water surface. Twenty-five samples were collected per trip for phytoplankton enumeration and identification.

Table 45. Sampling Station Location and Depth

Station number	*Location*	*Average depth (ft)*
1	Lake Catherine	39
2	Channel Lake	35
3	Lake Marie (east)	22
4	Lake Marie (west)	31
5	Bluff Lake	27
6	Petite Lake	17
7	Fox Lake (Stanton Bay)	4.4
8	Fox Lake (main)	7.2
9	Fox Lake (Mineola Bay)	12
10	Nippersink Lake	4.9
11	Pistakee Lake	5.4
12	Pistakee Bay	30
13	Grass Lake (south)	3.7
14	Grass Lake (north)	3.3
15	Cedar Lake	42

Methods

Surface samples were collected with a bucket. Samples below the surface were collected with a Kemmerer sampler. Experience has shown that collection in this manner, in contrast to the use of a plankton net, produces a better representation of the naturally dispersed aquatic organisms. A bias in organism shape and size is avoided. A water sample volume of 380 ml was put in a small-mouth glass bottle, preserved with formalin, and stored at room temperature until examined.

Examinations were preformed within a week, at which time the sample was thoroughly mixed and a 1-ml aliquot pipetted into a Sedgwick-Rafter cell. An inverted phase contrast-microscope equipped with 10X eyepieces, 20X objective, and a Whipple disc was used for identification and counting purposes. Five short strips (about 280 fields) were counted. Dilution or concentration was not required.

Phytoplankton were identified to species by employing several keys (Palmer, 1959; Patrick and Reimer, 1966; Prescott, 1962, 1970; Smith, 1950; and Tiffany and Britton, 1951). They were classified in five main groups, i.e., blue-greens, greens, diatoms, flagellates, and desmids.

Types of Algae

Algae are classified, in part, according to their color. The blue-green algae are so named because, in addition to chlorophylls, they contain phycocyanin which gives them a blue to dark green tint. A red pigment is sometimes also present. They contain about 1500 species and may be autotrophic or heterotrophic. Most blue-green algae grow in nonfilamentous colonies or in branched or unbranched filaments. They are widely distributed and occur in varied habitats, but when they occur in massive numbers (a bloom), they are found at the water surface. They are more frequently found in lakes and ponds than in the running waters of streams.

The green algae usually contain one major group of pigments, the chlorophylls, and most are autotrophic. This group includes about 700 species. Although a number live in salt water, the group as a whole is more characteristic of fresh water. They may be either free-floating or attached and are usually either single cells or filamentous colonies. If numerous, they display a green cast to the water.

Somewhat between blue-green and green algae is a group known as diatoms. Diatoms are characterized by the presence of silica in their cell walls, and by the presence of green, yellow, or brown pigment associated with the chlorophylls depending on the stage in their life cycle. They vary in color from brown to green. There are about 16,000 species. The cell wall is composed of two halves (valves) one overlapping the other like the top and bottom of a pill box. Generally the cell is oblong to circular, although there can be a variation in shape.

In several divisions of algae, including some greens, there are species that are unicellular and equipped with flagella. Flagella are a whiplike organ that make mobility possible. The organisms so equipped are flagellates. They are motile and may be either autotrophic or heterotrophic. The cells range from spherical to ovoid depending on the species. They are most commonly found in organically enriched waters.

Desmids belong to the subgroup *Desmidiaceae* of the green algae. They are characterized by cells of distinctive shapes, one half of which corresponds in shape, size, and contents to the other half. In many desmids the two 'semicells' are connected by a short narrow tube (isthmus). They are numerous species of desmids and they are usually associated with lakes and ponds.

For enumeration, in general, blue-green algae were counted by the number of trichomes. Green algae were counted by individual cells except *Actinastrum, Coelastrum,* and *Pediastrum,* which were recorded by each colony observed. *Scenedesmus* was counted by each cell packet. Diatoms were counted as one organism regardless of their grouping or connections. For instance, a unit was considered to be a filament of *Melosira,* a cluster of *Asterionella* or *Fragilaria* cells, or single cells of *Stephanodiscus* or *Surirella.* For flagellates, a colony of *Dinobryon* or a single cell of *Ceratium* was recorded as a unit.

Algal Composition

During the 5-month collection period, 64 algal species were recovered from 414 samples. The species included 6 blue-green algae, 18 green algae, 29 diatoms, 9 flagellates,

Table 46. Occurrence and Type of Algae at Sampling Locations

(Percentage of time present at sampling locations)

Algal type	Station number* 1A	1B	1C	2A	2B	2C	3	4A	4B	4C	5	6	7	8	9	10	11	12A	12B	12C	13	14	15A	15B	15C	Number of stations
Blue-green algae																										
Anabaena spiroides	47	31	13	32	19		11		6		11	32	16	5	5	5		5	6		16	11	14	14		19
Anacystis cyanea	11																									1
A. flos-aquae	26	13	6	11	19	6	37	31	31	13	37	58	37	37	26	21	16	32	25	31		5				21
A. thermalis	11	13	13	26	31	19	26	27	38	38	37	37	26	21	16	16	21	26	31	19						20
Aphanizomenon flos-aquae	95	81	56	74	88	63	68	58	50	38	58	68	53	47	37	58	47	47	19		63	47	57	43	29	24
Oscillatoria putrida																							14			1
Green algae																										
Actinastrum hantzschii								5							5	5	11				21	21				6
Ankistrodesmus falcatus													5		5	11		5	6		16	11	29	14	14	10
A. convolutus																					5					1
Chlorella ellipsoidea							5				5															2
C. pyrenoidosa							5																			1
Coelastrum microporum	11	6									5	5	11	5	5			11			5	5				10
Crucigenia rectangularis											5		5								16					3
Oocystis borgei	16	13	6	11			21	26	6		11	16	32	11	11	11	11	11	6	6		16				18
Pediastrum duplex	11						16	11	6		16	21	32	11	5	26	21	16	13		11	26			14	16
P. simplex		-	13					11					5	11	5		11	5			11	11				9
Scenedesmus carinatus														5		11		5			5					4
S. dimorphus	5						16	5		6	5	5	11	16	5	16	16		6	13	74	47				15
S. quadricauda													5													1
Sphaerocystis schroeteri					6							5														2
Tetraedron limneticum		13	6	11	6	6	21	32	19	6	21	32	16	11	11	11	5	5	6			5				19
T. sp.	5																									1
Ulothrix variabilis	16	6			6	6	11	11	13		16	11	37	37	32	32	42	21	21	38	26	21		14	14	21
U. zonata														5												1
Diatoms																										
Asterionella formosa							11	11	6		11	11		5		5	5									8
Caloneis amphisbaena		6	6							13	5								6	6	5					7
Cyclotella acellata																	5	5								2
C. glomerata																		5			5	5	14	14	14	6
C. meneghiniana	16	25	31	32	13	13	42	63	44	44	37	37	37	79	53	89	68	37	31	31	95	95				22
C. michiganiana	5						5		6													5			14	5
Cymbella mixicanum						6										5										2
Diploneis interrupta													5													1
D. smithii			6																							1
Gomphonema olivaceum																5						5				2
Gyrosigma kutzingii														5			5									2
G. wormleyi			6																							1
Melosira ambigua															5	5										2
M. granulata	11	19	13	16	13	13	26	47	25	31	26	47	63	74	47	58	74	74	81	50	58	37				22
Navicula gastrum	5					6															16	5				4
N. gracilis	5							5	1			5	5													5
N. odiosa																	11				5	5	14	14	14	6
N. peregrina														5												1
N. sp.													5													1
Neidium dubium																5										1
N. productum																	5									1
Nitzschia acicularis														5												1
N. angustata																		5					14			2
N. denticula																					5					1
Stephanodiscus niagarae			6				11	5					11		16	5	5	5			5	5				10
Surirella ovata								5	6									5	6		5					5
Synedra acus						6		11	6								5			6		11				6
S. ulna		6	6									5		5		5				6	5					7
Tabellaria fenestrata			6	5																	5		57	43	43	6
Flagellates																										
Ceratium hirundinella	63	75	44	74	63	38	37	32	25	13	21	16	5	5	5	5					5	5	14			19
Chlamydomonas sp				5																						1
Dinobryon sertularia																							14			1
Eudorina elegans																		5								1
Euglena gracilis								5					5	5		5			6							5
E. oxyuris														5								5				2
E. viridis	5			5			5	11		6		11			11	11	5			6	37	21		14		13
Gymnodinium sp	5													5			11	16	6							5
Phacus pleuronectes		6											11	5	11		5				26	5				7
Desmids																										
Cosmarium ponamense								5																		1
Staurastrum cornutum														5												1
Number of species	19	14	16	12	10	11	18	21	16	10	17	18	23	26	20	24	22	21	16	11	26	25	10	8	8	
Number of samples	19	16	16	19	16	16	19	19	16	15	19	19	19	19	19	19	19	19	16	16	19	19	7	7	7	

*A = surface, B = mid-depth; C = deep. Unlettered station numbers are surface samples

and 2 desmids. The occurrences and types of algae observed are listed in table 46. The number of species per sampling location, excluding Cedar Lake, ranged from 10 at Channel Lake mid-depth and Lake Marie (west) deep stations to 26 at Fox Lake (main lake) and at Grass Lake (south side).

As shown in table 46, the occurrence of desmids was negligible. Blue-green algae were predominant in most of the lakes. The most frequently occurring species was *Aphanizomenon flos-aquae*, noted in 24 of the 25 sampling stations. It did not occur in the deep waters of Pistakee Bay. *Anacystis* and *Anabaena* occurred frequently at some locations.

For the two locations sampled on Grass Lake, diatoms were predominant. The most common were *Cyclotella meneghiniana* and *Melosira granulata*. These two species are commonly recovered in Illinois streams (Lin et al., 1972, 1973, and 1975). The green algae, *Ulothrix variabilis, Tetraedron limneticum,* and *Oocystis borgei* occurred at most of the stations. *Scenedesmus dimorphus* was one of the most common algae in Grass Lake. The only flagellate of importance was *Ceratium hirundinella,* and its bloom concentration was confined to Lake Catherine and Channel Lake.

The recovery rates of the 17 most predominant algae at 25 sampling locations are depicted on figure 105. This figure is a partial summary of data tabulated in table 46.

Algal Density

The average composition for each algal type at each station, based on algal density, is shown in table 47. Also included is the maximum percentage composition of the four major groups for each sampling location. As shown, the blue-green algae were the most common in the deeper northernmost lakes (Lake Catherine, Channel Lake, Lake Marie, Bluff Lake, and Petite Lake). Several samples taken from these stations consisted solely of blue-green algae.

Table 47. Percentage Composition of Algal Types Based upon Algal Density

		Average				*Maximum*			
	*Sampling station**	*Blue-green*	*Green*	*Diatom*	*Flagellate*	*Blue-green*	*Green*	*Diatom*	*Flagellate*
1A	Lake Catherine	67.0	8.6	8.9	15.5	100	77.1	47.8	64.8
1B	Lake Catherine	64.2	3.8	11.0	21.0	100	22.7	45.5	86.9
1C	Lake Catherine	55.2	8.1	16.3	20.4	100	63.6	81.3	100
2A	Channel Lake	59.3	4.4	15.7	20.6	100	67.4	89.7	71.0
2B	Channel Lake	70.9	4.1	8.4	16.6	100	64.4	57.1	78.9
2C	Channel Lake	62.2	5.8	13.9	18.1	100	80.0	100	100
3	Lake Marie (east)	55.3	10.6	29.2	4.9	100	46.1	100	32.1
4A	Lake Marie (west)	56.6	7.2	29.7	6.5	100	35.5	100	62.5
4B	Lake Marie (west)	57.0	7.8	33.5	1.7	100	38.7	100	12.8
4C	Lake Marie (west)	59.4	1.8	36.7	2.1	100	15.2	100	25.0
5	Bluff Lake	66.5	12.2	20.0	1.3	100	67.6	68.2	9.3
6	Petite Lake	71.8	10.7	16.8	0.7	100	58.3	50.0	9.7
7	Fox Lake (Stanton Bay)	42.5	20.5	36.0	0.7	100	92.9	92.8	4.2
8	Fox Lake (main)	31.9	14.4	52.9	0.8	89.9	94.2	97.8	9.0
9	Fox Lake (Mineola Bay)	40.8	22.5	35.4	1.3	96.3	100	100	8.8
10	Nippersink Lake	32.6	16.5	50.6	0.3	94.6	88.9	96.6	4.7
11	Pistakee Lake	24.1	18.2	56.5	1.2	89.0	93.5	100	12.5
12A	Pistakee Bay	43.9	13.9	41.1	1.1	100	90.5	100	16.7
12B	Pistakee Bay	42.4	13.4	43.4	0.8	100	92.6	100	10.0
12C	Pistakee Bay	29.4	20.8	48.2	1.6	100	100	100	25.0
13	Grass Lake (south)	4.9	16.0	76.6	2.5	23.8	59.2	97.3	15.4
14	Grass Lake (north)	10.5	18.0	70.3	1.2	78.7	80.9	98.5	8.9
15A	Cedar Lake	28.9	11.4	56.6	3.1	69.2	79.9	100	20.0
15B	Cedar Lake	37.4	17.1	43.1	2.4	100	100	100	16.7
15C	Cedar Lake	16.1	25.0	58.9	0	87.5	100	100	

*A = surface; B = mid-depth; and C = deep; Unlettered station numbers are surface samples

In contrast, diatoms dominated the southernmost lakes, particularly Grass Lake. Flagellates averaged about 20 percent of the total for Lake Catherine and Channel Lake, but were not significant in other lakes. Except for a bloom of *Ulothrix variabilis* on

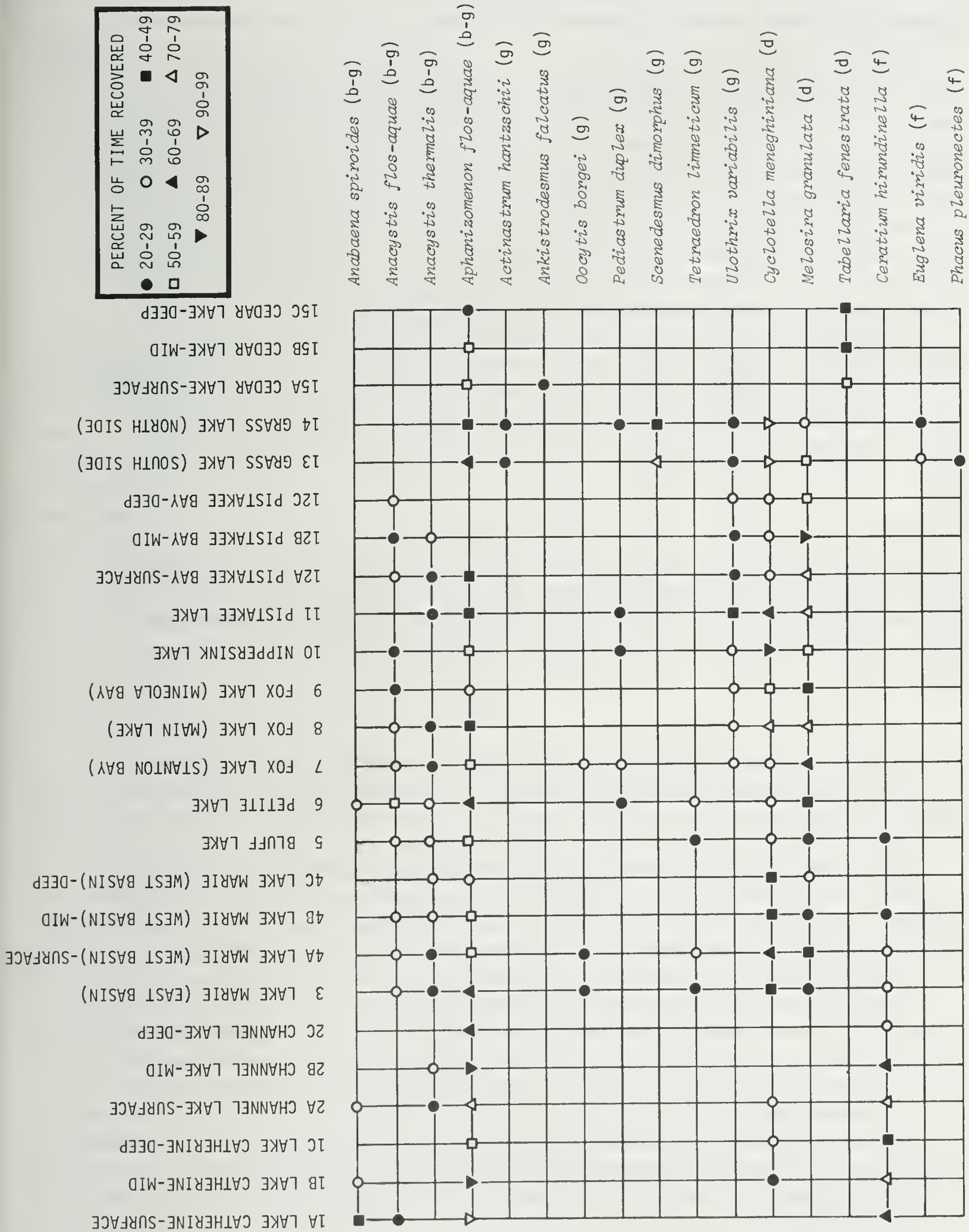

Figure 105. Occurrence of abundant algae in Fox Chain of Lakes

Pistakee Bay and Pistakee Lake on October 6, green algae were not an important factor in algal mass. The highest average percentage of green algae was 22.5 percent for Fox Lake at Mineola Bay.

The algal density data expressed as cell counts per milliliter (cts/ml), along with some other statistical results were calculated for each station. [These data are available upon request from the Illinois State Water Survey.] The observed total algal densities ranged from a low of 22 cts/ml for several locations to a high of 14,000 cts/ml in Fox Lake at Mineola Bay. Other stations having singularly high algal count were Channel Lake (surface) 13,000 cts/ml, Grass Lake (south) 11,000 cts/ml, and Fox Lake (main lake) 10,000 cts/ml.

Most algal counts for surface and mid-depth samples were in the range of 100 to 500 cts/ml except for Nippersink and Grass Lakes. In Grass Lake approximately 60 percent of the algal counts were more than 2000 cts/ml. As expected, the algal densities of the deep samples and of Cedar Lake were low, mostly below 100 cts/ml.

An examination of the algal density data for each station showed them to be generally distributed in a log-normal pattern. Therefore the central tendency and dispersion of the data were expressed in geometric terms. Excluding data of Cedar Lake, the geometric mean varied from a low of 65 cts/ml for Channel Lake (deep) to a high of 2200 cts/ml for Grass Lake (south). The geometric mean for Grass Lake (north) was also high (2000 cts/ml).

Diversity Index

There have been many methods suggested for defining the structure of a biological community. The most widely used procedure is the diversity index and the one most commonly used is Shannon's (1949) index. For this report the index for each sampling location on each day of collection was determined as follows (Hutchinson, 1967):

$$D = -\sum_{i=1}^{m} p_i \log_2 p_i$$

where $p_i = N_i/N_s$ and is the probability of the occurrence of the ith genera, N_i is the density of the ith genera, N_s is the total algal density of the sample, and m is the number of species per sample. For convenience $\log_2 p_i$ may be expressed as $1.44 \ln p_i$. The index, D, has a minimum value (zero) when m equals 1 and a maximum value when $m = N_s$.

The greatest species index developed was 2.62 for Grass Lake (south). Nine species of algae were observed in the sample. Diversity indexes of zero occurred for some samples. These were unispecies occurrences which were common in mid-depth and deep stations. The mean index ranged from 0.75 for Pistakee Bay (deep) to 1.32 for Petite and Pistakee Lakes excluding the control lake (Cedar Lake). In general, the index decreased with depth.

An attempt was made to correlate total algal density and species diversity index. Three models, i.e., linear, semi-log, and log-log, were evaluated for each sampling station. The value of 0.01 was used to replace zero in diversity index. Correlated coefficients are shown in table 48. Relatively high coefficients were found for only a few stations (1B, 1C, 2A, 2B, 10, and 14).

In a study of north-central Florida lakes, Brezonik et al. (1969) reported that species diversity is positively correlated (semi-log) with total plankton counts for Anderson–Cue Lake (an oligotrophic lake). This was not the case for lakes of the Fox Chain or for Cedar Lake.

Population Dynamics

This discussion relies mainly on the visual evidence of population succession depicted in figure 106a–l. As mentioned earlier the blue-green algae *Aphanizomenon flos-aquae* were the most dominant species in the waters of the Fox Chain. Their predominance is very well demonstrated in figure 106a–e. These figures are for the upper northern tier of lakes commencing with Lake Catherine and Channel Lake on down to and including Petite Lake.

In figure 106a and b (Lake Catherine and Channel Lake) there were 4 to 5 recorded major pulses of *Aphanizomenon flos-aquae*. These blooms commenced about June 6 and extended until about August 11. During this time the water temperature ranged from 20 to 26°C. Peculiar to these two lakes were two pulses of the flagellate *Ceratium hirundinella*. One of these pulses was recorded on July 21 at a water temperature of about 28°C and the other occurred on September 15 at a water temperature of about 18°C. This suggests the water temperature range for this flagellate is not a critical one. On these two lakes, also, a pulse or two of the blue-green *Anabaena spiroids* occurred. These occasions were the only ones where blooms of this particular algae were noted.

Table 48. Correlation Coefficient for Total Algal Density (X) versus Diversity Index (Y)

Sampling station	*Sample number*	*Linear* $Y=a+bX$	*Semi-log* $Y=a\exp(bX)$	*Log-log* $Y=aX^b$
1A	19	–0.55	–0.67	–0.56
1B	16	–0.27	–0.11	0.99
1C	16	0.33	0.94	0.18
2A	19	–0.56	–0.76	–0.50
2B	16	–0.57	–0.77	–0.57
2C	16	0.27	0.34	0.38
3	19	–0.10	–0.12	–0.13
4A	19	–0.14	–0.51	–0.75
4B	16	0.13	0.11	0.13
4C	15	0.11	0.33	0.42
5	19	0.13	0.13	0.18
6	19	0.30	–0.27	–0.32
7	19	–0.13	–0.12	–0.21
8	19	–0.52	–0.44	0.38
9	19	–0.30	–0.57	0.21
10	19	–0.10	–0.73	–0.11
11	19	–0.55	–0.57	–0.59
12A	19	0.14	0.11	0.09
12B	16	–0.47	–0.53	–0.17
12C	16	–0.34	–0.56	–0.38
13	19	0.42	–0.66	–0.23
14	18	0.16	0.22	–0.85
15A	7	0.63	0.39	0.47
15B	7	–0.33	–0.37	–0.29
15C	7	0.30	0.29	0.32

On Lake Marie (west), Bluff, and Petite Lakes (figure 106c–e) *Anacystis flos-aquae* pulses occurred from about mid-June until about the end of August. Water temperatures ranged from 20 to 25°C. These pulses were generally coincidental with larger *Aphanizomenon flos-aquae* blooms.

Differing however from Lake Catherine and Channel Lake, the three lakes for which data are depicted in figure 106 c–e supported another blue-green algae on September 15, *Anacystis thermalis*. The water temperature was about 18°C. According to Prescott (1962) this algae is usually found in soft or semisoft waters. This is not the case in the Fox Chain. Of the northern tier lakes only Lake Marie (west) supported a diatom population of any consequence. Minor populations of *Cyclotella meneghiniana* occurred as shown in figure 106c. This is probably due to the channel connection between Lake Marie and the northern portion of Grass Lake.

The main part of Fox Lake (figure 106f) did support a substantial population of *Aphanizomenon flos-aquae* during June. Thereafter the diatoms *Melosira granulata* and *Cyclotella meneghiniana* prevailed. Mineola Bay of Fox Lake supported three major *Aphanizomenon flos-aquae* blooms from about June 1 to August 1 (figure 106g). *Cyclotella meneghiniana* was prevalent thereafter. The algal population of Mineola Bay was similar to that maintained by Channel and Catherine Lakes in terms of blue-greens. Nippersink Lake (figure 106h) was more like the main part of Fox Lake (figure 106f) in that *Aphanizomenon*

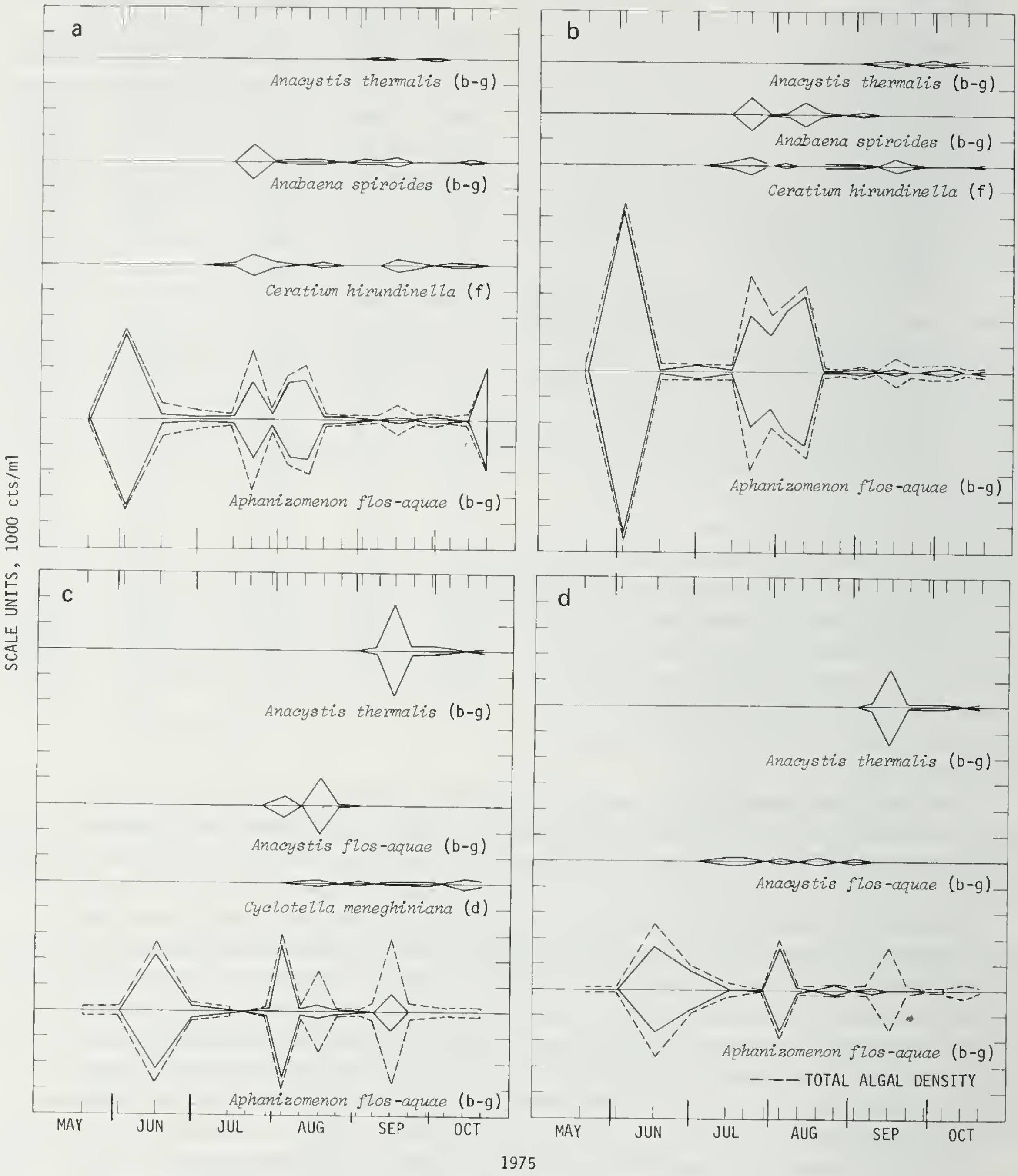

Figure 106a–d. Predominant algae at water surface in Lake Catherine (a), Channel Lake (b), Lake Marie–west (c), and Bluff Lake (d)

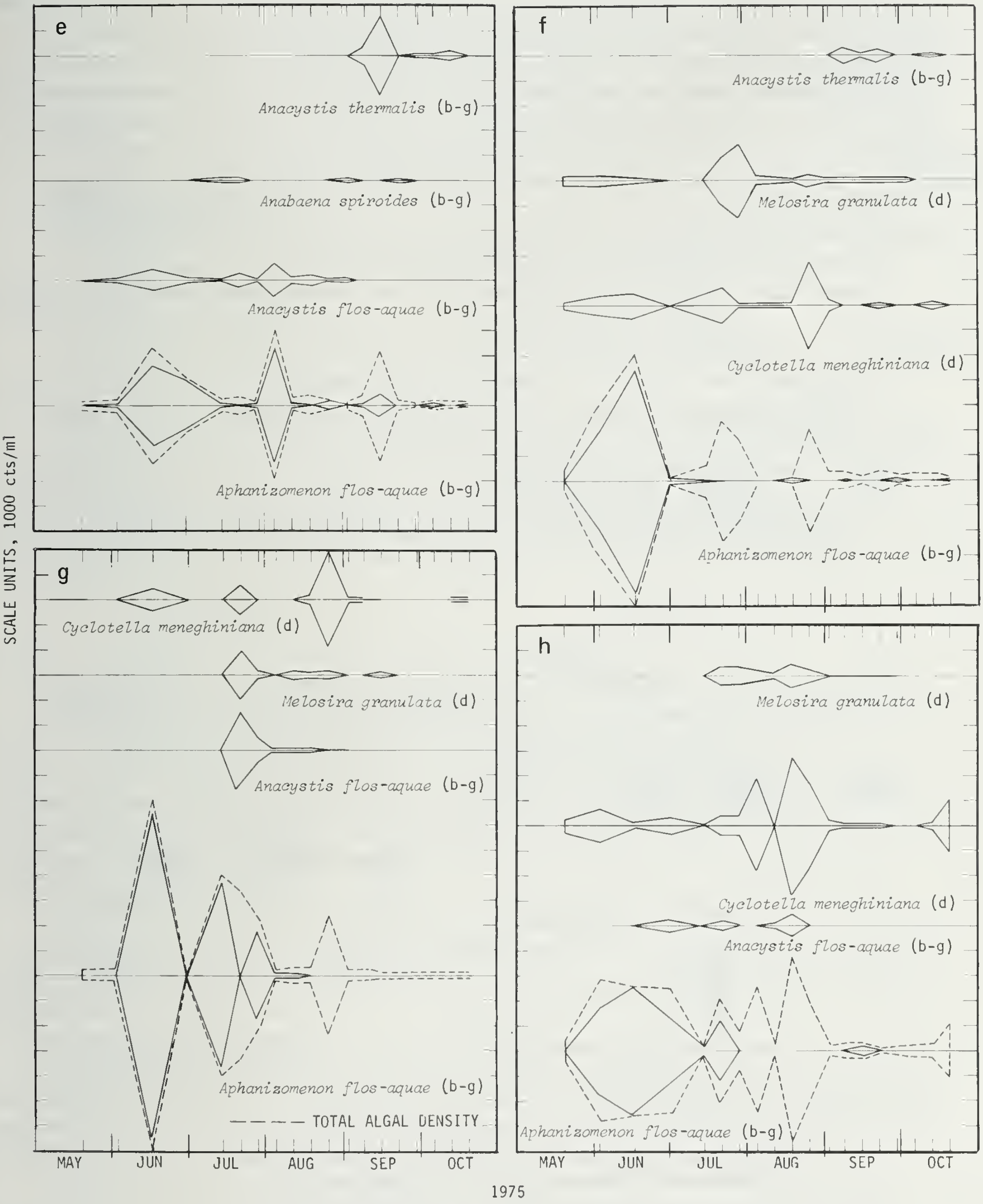

Figure 106e–h. Predominant algae at water surface in Petite Lake (e), Fox Lake–main body (f), Fox Lake–Mineola Bay (g), and Nippersink Lake (h)

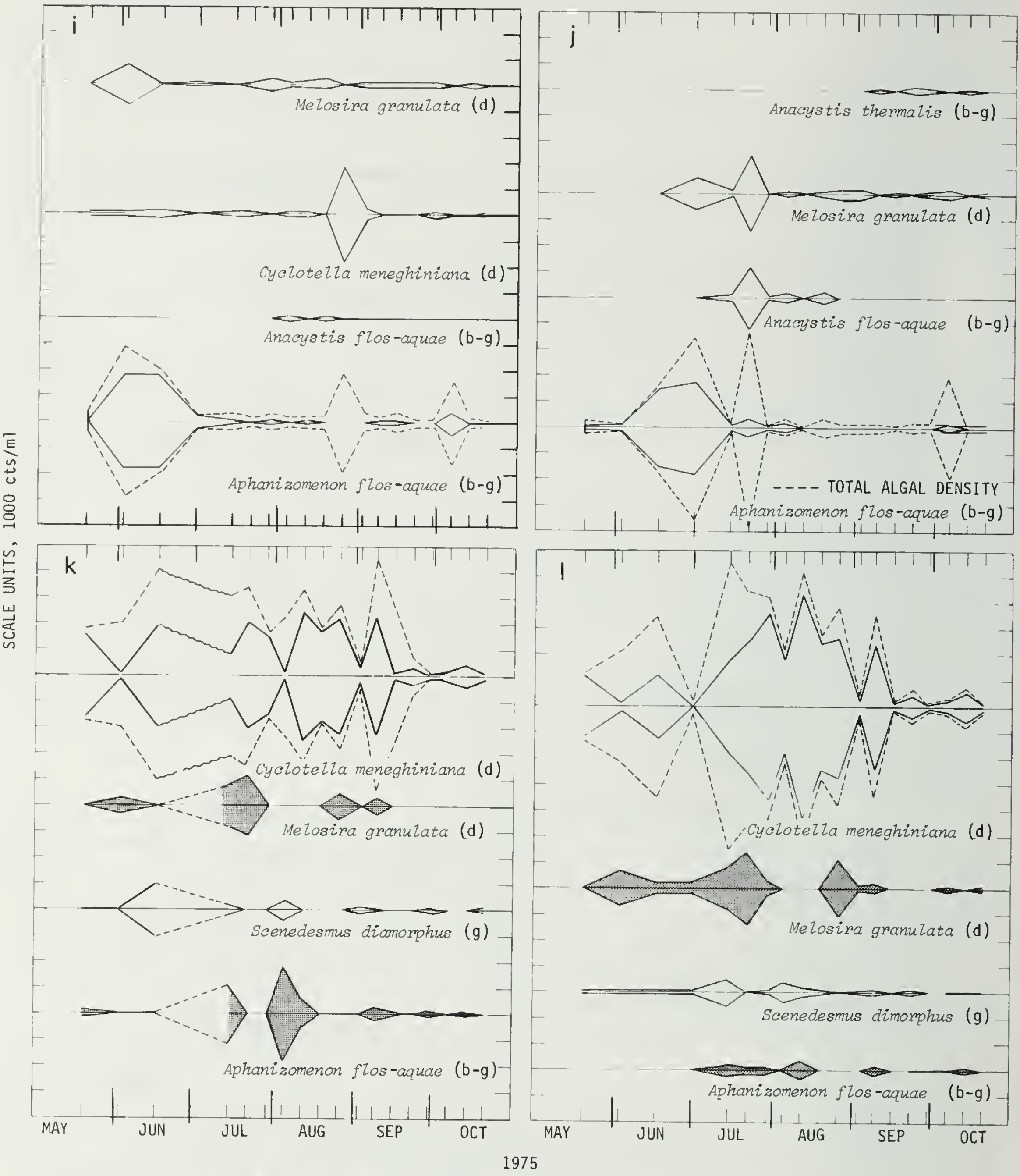

Figure 106i-l. Predominant algae at water surface in Pistakee Lake (i), Pistakee Bay (j), Grass Lake-north (k), and Grass Lake-south (l)

flos-aquae was more limited in June and *Cyclotella meneghiniana* was the prevailing diatom in August.

On Pistakee Lake blue-green algae were limited to June (figure 106i) with *Melosira granulata* and *Cyclotella meneghiniana* the important diatoms. Figure 106i suggests also that *Melosira granulata* is not incompatible with *Aphanizomenon flos-aquae* but *Cyclotella meneghiniana* may be. This is not clear-cut in figure 106f–h but the tendency leads toward such a conclusion. Pistakee Bay (figure 106j) supported a joint bloom of *Melosira granulata* and *Anacystis flos-aquae* on July 21 suggesting the environmental conditions for these differing types of organisms are similar.

It is obvious from figure 106k and l that the waters of Grass Lake are mainly diatom producers. *Aphanizomenon flos-aquae* did occur significantly during late July and early August, but *Cyclotella meneghiniana* was the predominant organism for June through October.

As mentioned earlier Cedar Lake has been considered a mesotrophic lake. Low algal densities as well as fewer species were recovered there. In fact, only two meaningful species were detected. The diatom *Tabellaria fenestrata* was recovered more than any other organism but was never found in significant numbers in any of the Chain lakes. The maximum at Cedar occurred at the water surface, at 270 cts/ml, on September 8. *Cyclotella meneghiniana* and *Melosira granulata,* the predominant diatoms in the Chain, were not recovered in significant numbers from Cedar Lake. The other important algae was *Aphanizomenon flos-aquae,* however, the density of this blue-green generally did not exceed 100 cts/ml.

Summary

Sixty-four algal species were recovered from 414 samples. The number of species per sampling location varied from 10 at Channel Lake and Lake Marie to 26 on Fox Lake (main) and Grass Lake. Blue-green algae were predominant and occurred at 24 of the 25 sampling stations. They consisted mainly of *Aphanizomenon flos-aquae.* The only flagellate of importance was *Ceratium hirundinella,* and significant concentrations of this organism were limited to Channel Lake and Lake Catherine. The only green algae bloom was created by *Ulothrix variabilis* on the waters of Pistakee Lake. Diatoms were quite significant on the shallower water bodies.

Algal densities ranged from about 25 to 14,000 cts/ml. The highest count occurred on Mineola Bay. Other high counts observed were 13,000/ml on Channel Lake; 11,000/ml on Grass Lake (south), and 10,000/ml on Fox Lake (main). In Grass Lake 60 percent of the collections had algal densities in excess of 2000 cts/ml. Most of these were the diatom *Cyclotella meneghiniana.*

The highest diversity index was developed from a collection on Grass Lake (south). Nine species of algae were in the collection. Mean diversity indexes ranged from 0.75 for Pistakee Bay to 1.32 for Petite Lake. A meaningful correlation between algal densities and diversity indexes did not exist.

The predominance of algal types, i.e., blue-green and diatoms, is related to the physical characteristics of the lakes. The lakes in the northernmost tier are relatively deep (20-40 feet), and their lesser expanse of areal water surface makes them less exposed to wind action than other lakes in the system. These lakes support similar algal types, mainly blue-greens. Likewise, other protected water bodies such as the bay areas of Pistakee Lake and Fox Lake mainly support blue-green algae.

The open expanse of the waters of Fox, Pistakee, and Nippersink Lakes, after an early June bloom of *Aphanizomenon flos-aquae,* mainly supported a diatom population. The shallow and expansive Grass Lake was principally a habitat for diatoms.

The importance of algal types and species for each body of water is shown in table 49. In the rating system, based upon concentration and frequency of occurrence, the lower the numerical rating, the greater its prominence on a corresponding body of water.

Table 49. Rating of the Most Important Algae for Each Water Body

	Blue-green				*Green*		*Diatom*			*Flagellate*
Location	Aphanizomenon flos-aquae	Anabaena spiroides	Anacystis flos-aquae	Anacystis thermalis	Scenedesmus dimorphus	Ulothrix variabilis	Cyclotella meneghiniana	Melosira granulata	Tabellaria fenestrata	Ceratium hirundinella
Lake Catherine	1	2								3
Channel Lake	1	2								3
Lake Marie (east)	1		2	3			4			
Lake Marie (west)	1		2	3			4	5		
Bluff Lake	1		3	2			4	5		
Petite Lake	1		2	3			5	4		
Fox Lake (Stanton Bay)	1		3	4			5	2		
Fox Lake (main)	3		4			5	1	2		
Fox Lake (Mineola Bay)	1		4			5	2	3		
Nippersink Lake	2		4			5	1	3		
Pistakee Lake (main)	3					4	1	2		
Pistakee Bay	2		4				3	1		
Grass Lake (south)	4				3		1	2		
Grass Lake (north)	2				2		1	4		
Cedar Lake	2								1	

Biological Characteristics – Benthic Organisms

Fourteen stations on the Fox Chain of Lakes were sampled on three separate dates (June 16, July 21, and September 8) in 1975. Three grabs with an Ekman dredge (6 x 6 inches) were taken at each station. The samples were then washed in a 30-mesh screen bucket, placed in quart jars, and preserved with 25 ml of formalin. In the laboratory, the samples were again washed in a 30-mesh sieve. The organisms were then picked from the bottom detritus, identified, counted, and preserved in 70 percent ethyl alcohol.

The benthos found at the sampling stations can be characterized as pollution tolerant organisms. The dipteran larvae *Chaoborus* is the predominant organism in most of the lakes. The *Chaoborus* (phantom midges) has air sacs which permit it to visit the surface waters to feed and renew its oxygen supplies at night. During the day, this organism burrows in the sediments and may survive there in great numbers, even in anaerobic conditions. *Chironomous* and *Procladius,* the other two principal components of the benthos, belong to the dipteran family Chironomidae (true midges). These larvae remain in the bottom sediments until just before emergence. Both of these genera have a hemoglobin-like blood pigment and special gills to extract sufficient oxygen from nearly anoxic waters. The predominence of the genera *Chironomous* and *Chaoborus* in the benthos has been associated with an advanced stage of eutrophication.

Community structure can be used to determine the health or balance of a given habitat. Community structure or diversity can be determined by relating the number of species and their populations. A diverse community has many species with relatively few individuals in each one. A simplified community, indicating harsh environmental conditions, has few species with high populations in each one. The community structure of the lakes sampled in this study exemplify the latter condition. Low dissolved oxygen and unstable benthic substrates contribute heavily to the harsh benthic environment.

Table 50. Benthic Organisms per Square Meter in the Fox Chain of Lakes

	Chaoborus				Chironomus				Procladius			
Lake	*6/16*	*7/21*	*9/8*	*Average*	*6/16*	*7/21*	*9/8*	*Average*	*6/16*	*7/21*	*9/8*	*Average*
Catherine	58	43	87	66	14			5				0
Channel		189	131	107				0	14			5
Marie (east)	14	29	218	87	14			5				0
Marie (west)		14	14	9	14			5				0
Bluff	43		116	53				0				0
Petite	29	72	594	232	102	14		39	131		43	58
Fox (Stanton Bay)	130	58		63	73	14		29	43	174		72
Fox (main)		43		14	87	14		34	14			5
Fox (Mineola Bay)			43	14	87	14	14	38	101	72	14	62
Nippersink				0				0				0
Pistakee (main)				0	275			92				0
Pistakee Bay			159	53				0				0
Grass (south)				0		44	29	24		29	87	39
Grass (north)				0			14	5				0

Chaoborus was found at all the sampling stations (see table 50) except Nippersink, Pistakee (main), and Grass (south and north). The absence of *Chaoborus* from these locations can be explained by the fact that these stations are located on the main dredged channel through the lake system. *Chaoborus* are not found in rivers or lakes with currents or high benthic turbulence.

Low dissolved oxygen concentrations limit the *Chironomous* and *Procladius* populations in the deeper lakes, i.e., Catherine, Channel, Marie (east and west) and Bluff. The intermediate depth, wind-mixed lakes (Petite and three stations on Fox) maintain a higher level of dissolved oxygen and exhibit a more constant and diverse community. Lake Nippersink showed the highest level of dissolved oxygen of any station and yet no benthic organisms were found there. It is a small, shallow lake and the sampling station was located on a heavily traveled, dredged channel. It is believed that the motor boat traffic churns the bottom sediments prohibiting the establishment of a benthic community. Pistakee (main) and Grass (north and south) show a reduced Chironomidae population. These stations have high dissolved oxygen concentrations, yet are still on dredged channels. They are able to maintain a limited benthic population mainly because of reduced boat traffic at these stations. The Pistakee Bay station is over a deep hole in an otherwise shallow lake. Its benthos are similar in character to the benthos of the deep lakes.

NUTRIENT BUDGET

Though nitrogen and phosphorus are not the only nutrients required for algal growth, they are generally considered to be the two main nutrients involved in the lake eutrophication process. In spite of the controversy over the role of carbon as a limiting nutrient, a vast majority of the researchers regard phosphorus as the most frequently limiting nutrient in lakes (Bartsch, 1972; Gakstatter et al., 1975; Malueg et al., 1973; U.S. Environmental Protection Agency, 1973; and Vollenweider, 1968).

Several factors have complicated attempts to quantify the relationship between lake trophic status and measured nutrient concentrations of the lake waters. For example, measured inorganic nutrient concentrations do not denote nutrient availability to the plant, but merely represent what is left over by the lake production process. A certain fraction of the nutrients (particularly phosphorus) while passing through successive biological cycles, become refractory. In addition, numerous morphometric and chemical factors affect the availability of nutrients in lakes. Factors such as mean depth, basin shape, and detention time affect the amount of nutrients a lake can absorb without developing nuisance conditions. Nutrient budget calculations represent the first step in quantifying the dependence of lake water quality on the nutrient supply. It is often essential to quantify the sources of nutrients from management and eutrophication control viewpoints. Thus Vollenweider (1968) and others have emphasized the importance of quantifying nutrient supply, particularly those of nitrogen and phosphorus, in determining lake trophic status.

A few nutrient budgets for lakes have been reported in the literature, e.g., Hetling et al. (1975) for Canadargo Lake in New York; Greeson (1971) for Oneida Lake in New York; McGauhey et al. (1963) for Lake Tahoe in California; and Sonzogni and Lee (1972) for Lake Mendota in Wisconsin. Vollenweider (1968) has summarized most of the budget calculations for European and North American lakes. Comprehensive evaluation of nutrient balance for a lake system requires measurement of all potential nutrient sources and sinks over an extended period to assess seasonal and other effects.

Potential sources of nitrogen and phosphorus for lakes are the watershed drainage which can include agricultural runoff, urban runoff, swamp and forest runoff, domestic and industrial waste discharges, septic tank discharges from lakeshore developments, precipitation on lake surface, dry fallouts (i.e., leaves, dust, seeds, and pollen), groundwater influxes, nitrogen fixation, sediment recycling, and aquatic bird and animal wastes. Potential sinks can include outlet losses, fish catches, aquatic plant removal, denitrification, groundwater recharge, and sediment losses. Some sources and sinks, e.g., groundwater, nitrogen fixation and denitrification, and nitrogen and phosphorus recycling from sediments, require elaborate sampling and experimental procedures for adequate evaluation. Consequently, manpower and time constraints have resulted in less than complete nutrient balance studies reported thus far.

A partial nitrogen and phosphorus budget is presented here. The budgets are referred to as 'partial' since no attempt was made to account for such sources of nitrogen and phosphorus as groundwater, leaves, pollen, seeds, or nitrogen fixation.

Nutrient emissions from municipal and industrial waste treatment plants in Illinois, contributing to the lake system either directly or through tributaries, were estimated by assessing the effluent quality characteristics. The nutrients transported by the Fox River and other tributaries to the Fox Chain of Lakes were measured by determining the weekly phosphorus and nitrogen concentrations in the streams in conjunction with the streamflow rates. Because the sampling sites were located on the tributaries close to the lakes, nutrient transport values estimated for the tributaries combine the contributions of point and nonpoint sources. Thus, knowing the total nutrient transport of the streams, and the municipal and industrial wasteflow contributions, the magnitude of nonpoint sources contribution could be estimated by difference. Nutrient contributions from precipitation were determined from phosphorus and nitrogen concentrations of rainwater samples collected periodically at three sampling sites in the area and from the total annual precipitation for the area.

The nutrient contribution from groundwater is considered to be insignificant compared with other sources. In Cedar Lake, which is entirely springfed, the nitrogen concentrations were found to be comparable to those found in the Fox Chain of Lakes. However, the phosphorus concentrations in Cedar Lake were much less. As discussed earlier, this was true even in the hypolimnetic zone of Cedar Lake which was anoxic during summer months.

Leaves have been reported as a source of phosphorus. Cowen and Lee (1973) reported that inorganic phosphorus was rapidly leached out of leaves collected in early autumn. Even leaves weathered by rainwater or lake water contained significant amounts of leachable phosphorus. A leaching rate of 54 to 230 micrograms (μg) of phosphorus per gram of leaves was reported by Cowen and Lee. The Fox Chain of Lakes and the interconnecting channels were observed on several occasions to be covered with leaves, cottonwood fuzz, seeds, and other dry fallouts. Nutrient contributions from these fallouts and from aquatic bird wastes could not be readily evaluated.

Contributions from Precipitation

The nitrogen and phosphorus concentrations measured in rainwater samples collected from three locations in the Fox Chain of Lakes area are shown in table 51. For comparison, analyses of rainwater samples collected at the site of the Water Quality Section's laboratory in Peoria is also shown in the table. Even though the analyses were made on rainwater samples only, these results are equally applicable to snow samples. Murphy (1974) investigated the phosphorus content in rain and snow in the Chicago area and found the concentrations of phosphorus were similar. The mean concentrations of nitrate nitrogen, ammonia nitrogen, Kjeldahl nitrogen, and total phosphorus in rainwater, based on all the observations made in the Fox Lakes area, are 0.93, 2.02, 2.71, and 0.41 mg/l, respectively. The long-term average annual precipitation at Antioch in the Fox Chain of Lakes area, as reported by the National Weather Service, is 33 inches. The annual rate of nitrate, ammonia, and total phosphorus addition, expressed as pounds per acre of lake surface per year (lbs/ac/yr), due to direct precipitation amounts to 6.61, 15.10, and 2.84, respectively. The Fox Chain of Lakes with a total surface area of about 6850 acres receive annually 44,600 lbs of nitrate, 103,400 lbs of ammonia, and 19,500 lbs of total phosphorus from direct precipitation.

Murphy (1974) reported a rate of 0.22 lbs/ac/yr of total phosphorus input from precipitation (29 inches) in the Chicago area. Sonzogni and Lee (1972) have reported

Table 51. Rainwater Quality Characteristics at Four Locations in Illinois

(in milligrams per liter)

Location	*Number of analyses*	*Range*	*Mean*	*Number of analyses*	*Range*	*Mean*
		Nitrate-N			**Kjeldahl-N**	
Antioch	11	0.26-2.90	0.77	9	0.65-5.01	2.88
Chain of Lakes State Park	8	0.32-1.58	0.81	3	1.81-11.10	5.45
Lake Villa	16	0.37-2.43	1.11	9	0.85-6.03	2.53
Peoria	6	0.30-0.85	0.53	3	0.46-1.22	0.86
		Ammonia-N			**Total phosphorus**	
Antioch	11	0.38-4.78	2.22	11	0.12-0.64	0.27
Chain of Lakes State Park	8	0.32-5.67	1.97	8	0.00-0.70	0.32
Lake Villa	14	0.40-4.82	1.90	14	0.03-2.09	0.56
Peoria	6	0.34-1.07	0.68	5	0.04-0.41	0.17

loading rates of 2.9 lbs/ac/yr for nitrate, 2.5 lbs/ac/yr for ammonia, and 0.21 lbs/ac/yr for total phosphorus to Lake Mendota (Wisconsin) from atmospheric precipitation (30 inches). The U.S. Environmental Protection Agency (1973) has reported rates of nitrogen contribution from precipitation comparable to rates found in this study for other midwestern cities. However, the phosphorus rates summarized in that report are much less than those obtained in this study.

Contributions from Septic Tanks

Septic tank field-tile systems are generally a problem only if they become clogged or water-bound which is likely to occur in non-sandy soils such as the types found in the Fox Chain of Lakes area. When this occurs, surface discharge results, and nutrients in the effluent can be transported via overland flow to the lakes. Local residents have reported such occurrences that are apparent in winter under snow-cover conditions.

In the absence of detailed field measurements to quantify the nutrient contribution to the lakes from septic systems, an indirect approach in estimating the nutrient contribution was taken here. It was reported earlier that there are about 6900 residential units around the lakes that use septic systems, and institutions like schools, churches, hotels, restaurants, and other commercial enterprises contribute an estimated daily wasteflow of 155,000 gallons. This wasteflow is equivalent to that flow from a population of 1550 persons at the rate of 100 gallons per capita per day. Further, assuming an average occupancy of three persons per residential unit, the total number of humans contributing to wasteflow could be 22,250. Therefore, the assumption here is that 22,250 persons are served by septic tanks.

Phosphorus and nitrogen contribution rates, in terms of pounds per capita per year (lbs/cap/yr), used in estimating the impact of septic tank systems by different investigators have differed significantly. Sonzogni and Lee (1972) used rates of 3.0 lbs/cap/yr for soluble orthophosphorus; 4.5 lbs/cap/yr for total phosphorus; 6 lbs/cap/yr for inorganic nitrogen; and 8 lbs/cap/yr for total nitrogen in estimating septic tank contributions to Lake Mendota in Wisconsin. The U.S. Environmental Protection Agency (1973) recommends rates of 3.3 lbs/cap/yr for total phosphorus and 14.3 lbs/cap/yr for total nitrogen with the suggestion to reduce these values to account for seasonal occupancy, lack of laundry facilities, and other factors. Shannon and Brezonik (1972) employed rates of 8.7 and 1.75 lbs/cap/yr for nitrogen and phosphorus, respectively, in estimating nutrient input from septic tank systems around 55 lakes in Florida. The rates used by Sonzogni and Lee for Lake Mendota were used in this investigation to evaluate the impact of septic tank disposal systems.

The McHenry County Public Health Administrator estimates that about 10 to 20 percent of the septic tank systems in the Pistakee Lake area could be malfunctioning (William Mellon and Richard Wissell, personal communication 1976). If we use a failure rate of 20 percent for the entire Fox Chain of Lakes area, the amount of nitrogen and phosphorus added to the Fox Chain of Lakes from malfunctioning units are estimated to be: inorganic nitrogen, 26,700 lbs/yr; total nitrogen, 35,600 lbs/yr; dissolved orthophosphorus 13,400 lbs/yr; and total phosphorus 20,000 lbs/yr.

Nutrient Balance

An inventory of nutrient emissions to the Fox Chain from major point sources within Illinois is shown in table 52. The average emission rates in terms of pounds per day for ammonia, nitrate, organic nitrogen, dissolved orthophosphorus, and total phosphorus are shown in this table. Total inorganic nitrogen and dissolved orthophosphorus, which are the readily available forms of plant nutrients discharged by the Woodstock northside treatment plant, were the highest among the observed values. These were followed by the discharges from the Round Lake Sanitary District waste treatment plant.

Table 53 shows the nutrient loads transported by the Fox River and other tributaries to the Fox Chain of Lakes. The nutrient loads transported by the streams are further classified as to point or nonpoint sources. Because no detailed inventory of point nutrient sources in Wisconsin was made, the nutrients transported by the Fox River into the Fox Chain of Lakes are all shown as from nonpoint sources. The relative importance of point sources and nonpoint sources in nitrogen and phosphorus contributions is also shown in the table.

Nutrient flux from major sources to the Fox Chain of Lakes is shown in table 54. Rates of transport in tons per year for ammonia, nitrate, total nitrogen, dissolved orthophosphorus, and total phosphorus are listed. Tributaries to the Fox Chain, direct waste discharge, impact of septic tank disposal systems, and precipitation were the major sources of nutrients considered in this investigation. The sum of the first eight items in the list indicates the annual gross loading rates of nutrients. Data pertaining to the Fox River at Johnsburg indicate the magnitude of nutrients transported away from the Fox Chain. The

Table 52. Inventory of Point-Source Nutrient Emissions

		Ammonia-N		*Nitrate-N*		*Organic-N*		*Total phosphorus*		*Dissolved orthophosphorus*	
Treatment plant	*Mean flow (mgd)*	*Mean concentration (mg/l)*	*Load (lbs/day)*	*Mean concentration (mg/l)*	*Load (lbs/day)*	*Mean concentration (mg/l)*	*Load (lbs/day)*	*Mean concentration (mg/l)*	*Load (lbs/day)*	*Mean concentration (mg/l)*	*Load (lbs/day)*
Hebron Trickling Filter Plant	0.10	10.05	8.38	11.95	9.97	9.06	7.56	13.54	11.29	10.50	8.76
Hebron Lagoons	0.09	6.91	5.19	1.03	0.77	12.41	9.32	3.83	2.87	2.68	2.01
Richmond	0.15	8.69	10.87	4.79	5.99	3.86	4.83	9.24	11.56	5.57	6.97
Woodstock, Northside Plant	2.00	13.05	217.67	0.55	9.17	4.06	67.76	7.56	126.10	5.68	94.74
Woodstock Die Casting Company	0.55	0.19	0.87	1.70	7.80	1.84	8.45	2.82	12.94	2.30	10.55
Lake Villa	0.15	4.68	5.85	4.19	5.24	2.71	3.39	7.02	8.78	4.38	5.48
Round Lake Sanitary District	1.60	15.15	202.16	0.56	7.47	9.32	124.44	5.09	67.92	4.18	55.78
Antioch	0.75	5.84	36.52	5.17	32.34	5.40	33.80	5.91	36.97	4.37	27.33
Fox Lake	0.25	14.08	29.36	1.60	3.34	6.14	12.81	7.11	14.82	4.83	10.07

Table 53. Nutrient Loads Transported by the Fox River and Other Tributaries

(Nutrient loads in pounds per day)

	Ammonia-N		*Nitrate-N*		*Total nitrogen*		*Dissolved orthophosphorus*		*Total phosphorus*	
Stream	*Point source*	*Nonpoint source*	*Point source*	*Nonpoint source*	*Point source*	*Nonpoint source*	*Point source*	*Nonpoint source*	*Point source*	*Nonpoint source*
Inflow										
Fox River at Route 173		1010		5354		10,874		428		1187
Lily Lake Drain		3		14		45		0.45		1.7
Nippersink Creek	243	43	34	1337	375	2,021	123	4	165	58
Sequoit Creek	37	17	32	20	103	46	27	6	37	24
Squaw Creek	208	3	13	155	349	224	61	46	77	54
Total nutrient inflow	488	1076	79	6880	827	13,210	211	476	279	1325
Percentage*	3.5	7.7	0.6	49.0	5.9	94.1	13.2	29.7	17.4	82.6
Outflow										
Fox River at Johnsburg		1391		4738		10,723		509		1093

*Computed with respect to total nitrogen or total phosphorus as the case may be

Table 54. Nutrient Balance for Fox Chain of Lakes

(Rates in tons per year)

Sources	*Ammonia-N*	*Nitrate-N*	*Total nitrogen*	*Dissolved orthophosphorus*	*Total phosphorus*
Inflow					
Fox River at Route 173	184.3	977.1	1984.5	78.1	216.6
Lily Lake Drain	0.6	2.6	8.2	0.1	0.3
Nippersink Creek	52.2	250.2	437.3	21.7	40.7
Sequoit Creek	9.9	9.5	26.8	6.0	11.1
Squaw Creek	38.5	30.7	104.6	19.5	23.9
Fox Lake WTP	5.4	0.6	8.3	1.8	2.7
Septic tank systems	6.7*	6.7*	17.8	6.7	10.0
Precipitation	51.7	22.3	113.2	4.9**	9.8
Gross loading rate	349.3	1299.7	2700.7	138.8	315.1
Outflow					
Fox River at Johnsburg	253.9	864.7	1956.9	92.9	199.5
Net loading rate	95.4	435.0	743.8	45.9	115.6
Percent retained	27.3	33.5	27.5	33.1	36.7

*Assumed inorganic nitrogen equally divided

**Assumed dissolved orthophosphorus 50 percent of total phosphorus

Table 55. Relative Importance of External Sources of Nutrients, in Percent

Sources	*Ammonia-N*	*Nitrate-N*	*Total inorganic nitrogen*	*Total nitrogen*	*Dissolved orthophosphorus*	*Total phosphorus*
Fox River at Route 173	52.8	75.2	70.4	73.5	56.3	68.7
Lily Lake Drain	0.0	0.0	0.2	0.0	0.0	0.1
Nippersink Creek	14.9	19.3	18.3	16.2	15.6	12.9
Sequoit Creek	2.8	0.7	1.2	1.0	4.3	3.5
Squaw Creek	11.0	2.4	4.2	3.9	14.0	7.6
Fox Lake WTP	1.5	0.0	0.4	0.3	1.3	0.9
Septic tank systems	1.9	0.5	0.8	0.7	4.8	3.2
Precipitation	14.8	1.7	4.5	4.2	3.5	3.1

difference between the gross loading rate and the nutrients carried away from the Chain of Lakes represents the amount of nutrients retained by the lakes or the net loading rate of nutrients to the lake system. It is seen that about 27 percent of total nitrogen and 37 percent of total phosphorus applied to the system are retained in the lake system.

The relative importance of the various sources of nutrient input is presented in table 55. In addition to the values for ammonia nitrogen and nitrate-nitrogen, percentage figures for total inorganic nitrogen are also given. These represent the readily available form of nitrogen for biological processes. The Fox River transports about 70 percent of inorganic nitrogen, and together with Nippersink and Squaw Creeks contributes about 93 percent of the total inorganic nitrogen. Also, these three streams contribute about 86 percent of the dissolved orthophosphorus with the Fox River applying about 56 percent. The impact of septic tank systems and precipitation appears to be equal as far as total phosphorus is concerned. Each contributes about 3 percent of the total.

The best available guidelines for relating the nutrient flux to water quality in lakes were first proposed by Vollenweider (1968). These guidelines were used subsequently by several investigators (Bartsch, 1972 and Gakstatter et al. 1975). According to Vollenweider, for lakes with mean depths of 5 meters (16.4 feet) or less, permissible loading levels of biochemically active nitrogen and phosphorus are, respectively, 1.0 and 0.07 g/m^2/yr. For the same average depth, loading rates greater than 2.0 g/m^2/yr for nitrogen and 0.13 g/m^2/yr for phosphorus are considered excessive from a eutrophication point of view. The overall mean depth of the Fox Chain of Lakes is 5.7 feet; therefore, the guidelines cited by Vollenweider are applicable to the Chain of Lakes. The loading rates of total inorganic nitrogen and dissolved orthophosphorus for the Chain of Lakes were found to be 54.0 and 4.5 g/m^2/yr, respectively.

The net loading rates, considering only the available nitrogen and available phosphorus retained in the lakes, were found to be 17.4 and 1.5 g/m^2/yr, respectively, for nitrogen and phosphorus. It is seen that even the net loading rates of biologically active nitrogen and phosphorus are about ten times greater than the excessive levels of nutrient loading rates suggested by Vollenweider. The total nitrogen and total phosphorus loading rates for Lake Mendota were reported to be 3.10 and 0.17 g/m^2/yr, respectively, and those for Lake Washington were 31.4 and 1.34 g/m^2/yr (Vollenweider, 1968). Lake Waubesa in Wisconsin was found to have nutrient loading rates comparable to the rates observed for Fox Chain of Lakes. These three lakes were classified as eutrophic.

The total nitrogen and total phosphorus loading rates contributed to the lakes by the Fox River are 65.0 and 7.1 g/m^2/yr, respectively. The Fox River inorganic nitrogen and dissolved orthophosphorus loading rates amounted to 38.0 and 2.6 g/m^2/yr. These loading rates are several orders of magnitude larger than the excessive loading rate suggested by Vollenweider and others. The importance of controlling nutrient influx through the Fox River is apparent. *Efforts to minimize eutrophic conditions by controlling all the other sources without curbing nutrients transported by the Fox River would be futile.*

Nutrients entering a lake become incorporated in various chemical and biological cycling processes. Part of the nutrients are utilized in the metabolism of organisms, i.e., phytoplankton, zooplankton, vascular plants, and fish, and on death and decay of the organisms the nutrients are liberated for reuse. Part of the nutrients remain in solution, part become temporarily or permanently incorporated in the bottom sediments, and part flow out of the lakes. Part of the nutrients that accumulate in the lake, after a period of years, become available in concentrations sufficient to support algal blooms.

Organic matter, whether derived from external sources or produced internally, decomposes and oxidizes in the aerobic parts of the lakes. Organic decomposition, during periods of large algal blooms and in anaerobic zones, occurs when the biological production exceeds the oxidizing capacity of the waters. This results in higher concentrations of organic detritus in the bottom sediments of deeper water areas. Highly productive areas as in bays and dug channels, also exhibit accumulations of organic debris.

When anaerobic conditions develop at the sediment-water interface, nutrients contained in the organic debris are released back into the water. Such 'internal loading' varies from one water body to another and may be very high in certain specific cases. Vollenweider concluded, based on his extensive studies of European and North American lakes, that internal loading is a more serious threat to small lakes than to big lakes, whereas external loading plays a more important part in bigger lakes.

Vollenweider (1968) estimated sediment nutrient release rates of 1.2 and 0.01 g/m^2/day for ammonia and phosphorus, respectively, under anaerobic conditions. Fillos and Swanson (1975) reported phosphorus release rates of 1.2 and 26.0 mg/m^2/day under aerobic and anaerobic conditions, respectively, for the Lake Warner, Massachusetts, sediment samples.

Sridharan and Lee (1974) reported from laboratory leaching experiments with Green Bay (Lake Michigan) sediment samples that release rates of orthophosphorus under anaerobic conditions were much higher than the rates of release under aerobic conditions. They also found that the leaching rates were inversely affected by the presence of orthophosphorus in the leaching medium. They further postulated that the anoxic orthophosphorus release resulted from chemical reactions which are most likely abiotic. Bannerman et al. (1975) experimented with intact core samples from Lake Ontario and found the inorganic phosphorus release rates to be about 0.2 mg/m² /day, and estimated that this release rate constituted a sediment phosphorus contribution amounting to 10 percent of the external phosphorus loading to the lake.

Nutrient release, particularly that of phosphorus from sediment, appears to have a significant bearing on the productivity of lakes especially those that experience thermal stratification. Peterson et al. (1974) reported on a lake restoration experience with Snake Lake in Wisconsin. Dilution and flushing of the lake basin was tried as a restoration technique, by induction of low nutrient groundwater flow. They established that equilibration with lake bottom sediments could easily supply the dissolved nutrients observed in the lake and concluded that dilution coupled with other management techniques like nutrient inactivation, dredging, etc., may be necessary to achieve long-lasting satisfactory results. The remarks of Stumm (1975) are pertinent here:

> "The concentration of phosphorus in a surface water cannot be predicted merely on the basis of the supply of phosphorus and hydrographic conditions. For the assessment of the potential synthesis of biomass in an ecosystem, under conditions where phosphorus is a growth-limiting nutrient, two gross parameters are pertinent: (1) the ultimate capacity for photosynthetic production is given by the total reserve of phosphorus in a body of water i.e., the quantity of soluble particulate, sestonic and accessible sedimentary phosphorus, (2) the productivity measures the rate of biomass production. Both of these parameters are influenced by the extent and rate of regeneration of phosphorus and its exchange with sediments."

As indicated earlier, anoxic conditions in the Fox Chain of Lakes exist in the areas where the depth of water columns exceed 15 feet. From the depth-area relationships developed for the lakes, the areal extent of the lake system with water depths greater than 15 feet at normal pool level was estimated as 440 acres. Assuming a phosphorus release rate of 10 mg/m² /day (Vollenweider, 1968) under anaerobic conditions, the amount of phosphorus released from the sediments to the overlying waters during the 5-month period of thermal stratification is estimated to be 2.673×10^6 grams or approximately 5900 pounds. This alone results in a phosphorus loading rate of 0.1 g/m² /yr for the entire lake system. The loading rate approaches the excessive loading rate from eutrophication viewpoint suggested by Vollenweider (1968). Phosphorus recycled from the sediments in deep water areas of the Fox Chain of Lakes alone appears to be adequate for sustaining algal blooms for a long period of time.

REHABILITATION SCHEMES

Previous Investigations

Investigations designed to determine the interrelationship of the many factors contributing to the ecological system of the Fox Chain of Lakes did not exist until the present investigation was undertaken. However, in order to present a historical perspective of the problems associated with the lakes, a brief review of the previous studies is presented here.

It appears that in most instances past investigations were limited to a 2 to 3 day period and were predicated upon complaints, or had as an objective some other single facet associated with the waters such as fish population or bacterial densities. Most of the water chemistry data, temperature, and dissolved oxygen measurements have been incidental to the main purposes of the investigations. No examination of bottom deposits for nutrient material or organic content has been previously undertaken. With the exception of the Lake County Health Department 14-month study (1963-1964) regarding a nutrient budget for the Chain, there does not appear to have been a long-term study with the objective of determining specifically the principal factors which stimulate and sustain annually nuisance algal blooms.

Lake County 1962 Report. A report by the Lake County Health Department (1962) summarizes its observations in an effort to evaluate the quality of lake and stream waters in the county that might affect public health. Solely on the basis of bacterial densities, it was concluded that " . . . at present the streams rather than the inland lakes, are the source of concern . . . . While Lake County bathing beaches are reasonably free from bacteria, they are not free from algae blooms . . . . The Chain O'Lakes was not extensively evaluated [in 1959] because little data had been collected from these lakes at that time . . . ." The report also noted, "A special study was conducted on eight selected lakes, i.e., Cedar Lake, Long Lake, Third Lake, Loch Lomond, Bangs Lake, Slocum Lake, Lake Zurich, Diamond Lake, on a year round basis. The study concluded that although adding effluent which has been properly purified and chlorinated to lakes probably is not a danger to the health of the public, it often accelerates the natural aging process, eutrophication."

Public Health Service Report. The U.S. Public Health Service (1963) in its memorandum report summarized a 2-day sampling program and set forth some chemical and biological data. The probable causes of the algal problem existing at that time in the lake system was stated to be 1) shallow depths of the lakes, 2) influx of nutrients, 3) extensive canalization of low areas of the lakes, 4) septic tank drainage at the lakes' edges, 5) climatic conditions including low streamflows, and 6) the recirculation of nutrients from the bottom muds. The bloom was of *Aphanizomenon flos-aquae.* The conclusions reached were:

1) "The several lakes of the Fox Chain are biologically overproductive as manifested by algal blooms of such density and quality as to cause nuisance conditions and concomitant devaluation as aesthetic and recreational resources."

2) "The algal condition in 1963 was caused by a combination of low flow in the Fox River and fertilization from three principal sources: (a) treated sewage from the villages of Antioch, Fox Lake, and Round Lake; (b) infiltration of septic tank absorption field in unsewered residential areas; and (c) agricultural runoff in the drainage basin and from the nutrient rich waters of the Fox River."

3) "According to Dr. Baker, no serious health hazard existed. However, the quality was so poor as to be undesirable for bathing and aesthetic enjoyment."

> 4) "A program to remedy the problem should be initiated immediately. Such a program must involve the best informed technical talent available and will require the full cooperation of local residents as well as the assistance of federal and state agencies having capabilities in this field."

The remedial measures proposed consisted of a combination of actions, some of which could be taken immediately and others on a long-term basis. These, as stated, were as follows:

> "A wide area master sewage plan should be developed as soon as possible. This master plan should provide for the proper collection, treatment, and ultimate disposal of domestic and industrial waste waters, and it should encompass all of the area of the Fox River watershed that is within the Chicago Metropolitan area, rapidly becoming urbanized. The plan should identify strategic points at which waste waters can be discharged with minimum detriment to the stream, and analysis should be made of the impact of waste loads on the system, for both present and projected future loads. This does not mean that a single sewerage system must be built for the whole area. It does mean, however, that coordinated planning should be done for the whole area. Piecemeal planning by individual municipalities, or even by single counties, will not produce an adequate plan, as the water does not respect political boundaries. In addition, piecemeal planning will not receive the widespread acceptance essential to promulgation.
>
> "Reduction in present nutrient contributions will be required if the waters of the Chain of Lakes and the Fox River are to be improved. This can be accomplished by the elimination of septic tanks in built-up areas, especially those draining to the lakes; by construction of intercepting sewer systems; and by changing locations of wastewater outfall points to bypass the lakes and discharge to flowing streams. Concentrations of nutrients might also be reduced by placing restrictions on the operation of high-speed motor boats that may cause resuspension of nutrients from the bottom sediments. Bottom-feeding fish, such as carp and catfish, may also cause resuspension of bottom sediments. The possibility of removal of bottom-feeders, and restocking with more desirable species should be investigated. Future construction of long, narrow embayments where stagnant water conditions develop should be prohibited.
>
> "Institution of the foregoing measures as soon as practicable should result in considerable alleviation of the presently unsatisfactory conditions. Further progress toward restoration of the subject waters will require several long-range approaches. If determined feasible from an engineering viewpoint, the organic sediments in the lakes should be dredged and the spoil used for filling or diking off the bordering marshlands. The possibilities for flow regulation by upstream storage that would augment low flow in the Fox River, and for further reduction in nutrient concentrations in wastewaters by additional treatment, should be investigated. The latter will require research to develop economically feasible techniques. The possibility should be explored of using biological controls such as stocking the lakes with plankton feeding fish or establishing rooted aquatic plants that will successfully compete with the algae for nutrients and light. No efficient methods of biological control are known at this time."

Illinois Conservation Department Report. The Illinois Department of Conservation (1964) report on fishery investigations primarily dealt with fish population in the Chain. Some limited data regarding water chemistry is presented in the report along with the observation concerning "The apparent depletion of abundance of submergent vegetation and the expanding problem of planktonic algae dramatizes the significance of the biological changes which are taking place." Conclusions other than those pertaining to the fish population consisted primarily of the following:

> "The main cause for concern at this time would be the future water quality. The increasing severity of planktonic blue-green algae blooms during the warm months indicates environmental conditions which approach stagnation in some lakes of the Chain causing fish mortality in areas, as a result of algae drift and decomposition. Low water flow caused by prolonged drought was a

> contributing factor to algae abundance in 1963. Because blue-green algae blooms are usually related to the influence of extra nutrients such as from sewage treatment plants and septic systems, it is recommended that a central sewage collection be expanded in the residential areas around these lakes and that sewage treatment plants' effluents be diverted away from the watershed leading into these lakes.
>
> "A regular program of water sample collections should be set up for the Chain, which would include chemical and biological analyses of the water. Permanent sampling stations and standardized sampling procedure should be a part of such a program. All public agencies concerned with the Fox Chain of Lakes area, be it conservation, health, boat safety, waterways, or recreational planning should coordinate and share their programs and information one with another."

Illinois Public Health Report. The Illinois Department of Public Health in its survey of the Fox River in Illinois (April, June, July 1964) presented an appraisal of bottom fauna existing in the Fox River basin. The report identifies sampling points and presents a list of those organisms collected. The investigator stated:

> "It is possible from a study of the interrelationship of the species of bottom-dwelling organisms and their individual responses to a pollution load to devise a system of stream classifications. Such a system acknowledges the degree to which an environment is capable of maintaining a state of balanced aquatic production."

Nine locations on the lakes and their tributaries were sampled. The stations and their classifications are as follows:

Fox Lake	Polluted
Pistakee Bay	Semi-polluted
Squaw Creek	Unbalanced
Fox-Petite Channel	Semi-polluted
Fox-Grass Channel	Polluted
Sequoit Creek	Semi-polluted
Nippersink Creek	Unbalanced
Fox River at Illinois Route 173	Semi-polluted
Fox River at Wisconsin-Illinois line	Unbalanced

The following criteria were used in classifying the streams and lakes:

- A clean or balanced environment is one in which conditions are maintained capable of supporting a great variety of organisms, mostly intolerant species, from various taxonomic groups.
- An unbalanced environment is one in which the balance of life, as described for a clean water environment, has been disrupted but not destroyed. The population numbers of some of the intolerant forms are reduced and an increase becomes apparent in some of the more tolerant forms.
- A semi-polluted environment is one in which the balance of life found in a clean water environment is destroyed. Intolerant forms are completely absent or reduced to a minimum and the environment is composed predominately of tolerant forms.
- A polluted environment is one in which only the very tolerant forms are able to exist. These are usually present in great numbers unless excluded from the environment by severe conditions.

Lake County Recent Study. Report of the nutrients study undertaken by the Lake County Health Department (1963-1964) has not yet been prepared. Preliminary findings indicate that the phosphorus load to the lake system was 295 tons annually. Of this, approximately 75 percent originated from the drainage area in Wisconsin. These figures and the phosphorus load transport values for other tributaries are found to be comparable to the values obtained in this investigation.

Eutrophication

Because one of the primary objectives of this investigation is to develop strategies to restore and manage the water quality of the Chain of Lakes which involve reversing or retarding the aging process of the lakes, it seemed desirable to review some information pertaining to the eutrophic process in general, and the lake restroation techniques tried elsewhere.

Eutrophication is a natural aging process that affects every body of water from the time of its formation. Many interacting factors contribute to the overall process of eutrophication — a term more widely known to mean the nutrient enrichment of waters. The eutrophication of a lake system consists of the gradual progression from one life stage to another based upon changes in the degree of nutrient input or productivity. The youngest stage of the life cycle is characterized by low concentrations of plant nutrients and little biological productivity. Such lakes are called oligotrophic lakes. At a later stage in the succession, the lake becomes mesotrophic, and as the life cycle continues the lake becomes eutrophic or highly productive. The final life stage before extinction is a pond, marsh, or swamp.

As a lake ages, the degree of enrichment by nutrient materials increases. In general, the lake traps a portion of the nutrients originating in the surrounding drainage basin. In addition, precipitation, dry fallout, and in certain cases groundwater inflow are contributing sources. The shore vegetation and higher aquatic plants utilize part of the inflowing nutrients, grow abundantly, and in turn trap the sediments. The lake gradually fills in, becoming shallower by the accumulation of plants and sediments on the bottom and smaller by the invasion of shore vegetation, and eventually becomes a dry land. The extinction of a lake is the result of enrichment, productivity, decay, and sedimentation.

Human activities, such as altering lake drainage basins, agricultural practices, deforestation, and urban development, have hastened the nutrient addition to natural waters. When the pollutants are of a nutritional type, the enrichment of the recipient water is greatly accelerated and the rate of aging is consequently greatly increased. In this way, cultural eutrophication can significantly alter the rate of the natural process and shorten the life expectancy of the affected body of water.

Because eutrophic lakes contain an abundance of available nutrients, biological production is high and results in nuisance growths which adversely affect man's use of the water body. Plants, particularly algae, are of primary concern because they utilize dissolved inorganic nutrients from the water and thus become primary producers of new organic matter on which aquatic animal life depends. In oligotrophic lakes the phytoplankton are represented by large numbers of a few species. An overabundance of algae is generally called an algal bloom. Lackey (1949) and later Fruh (1967) arbitrarily defined an algal bloom as 500 cts/ml of raw water sample.

With the increased productivity associated with accelerated rates of eutrophication comes the filling of the lake basins with organic materials which subsequently exert an increased oxygen demand on the overlying waters. The increased oxygen demand may result in total depletion of oxygen in the cooler bottom waters during the summer, accompanied by an increase in the products of decomposition, e.g., carbon dioxide, ammonia, hydrogen sulfide, and methane. These developing anaerobic conditions result in replacement of benthic organisms with less desirable types.

In addition to restricting fish populations, highly eutrophic lakes are undesirable aesthetically and with respect to water use. Algal blooms produce taste and odor problems and create unsightly surface scums which discourage water contact recreational activities. Accumulation of algal mats and dense weed growths are most pronounced near shore. The accumulated algal masses decay resulting in extremely foul smelling conditions.

In addition to their deleterious effects on aesthetic and recreational aspects of the lake, excessive planktonic growths affect water supply resources. They create color, taste, and odor problems in water supplies and increase the rate of clogging of filters at water treatment plants.

Certain blue-green algae have been shown to have toxic effects on fish and animals. Evidence also exists that skin irritation and gastrointestinal disturbances may result in humans from contact and ingestion of lake water in which algae exist in bloom proportions.

Frequent and excessive algal blooms and the concomitant undesirable aesthetic effects have become a chronic problem in the Fox Chain of Lakes and have been the source of public complaints in the past few decades.

The algal blooms form a floating scum on the surface when the wind and wave actions are absent. Presence of gas vacuoles in the blue-green algae causes these algal species to rise to the surface forming a surface film. The algal masses, upon exposure to sunlight, become bleached giving the appearance and consistency of latex paint. Floating globs of decaying algae have been observed throughout the summer period in the Fox Chain of Lakes.

The dominance of cyanophyta in the deep lakes of the Chain, low algal diversity indices, high oxygen demand of the organic sediments in the bottom of the lakes with the consequent depletion of oxygen in the hypolimnetic zones of deep lakes, high concentrations of nitrogen and phosphorus in the lake waters, and other telltale signs point clearly to the fact that the lake system has reached the advanced stage of eutrophication. There is an abundance of macrophytes in the littoral zones of Channel Lake and Lake Catherine and in several of the man-made channels. Only a few isolated patches of macrophytes exist in the channel connecting Grass and Fox Lakes.

An algal assay was carried out with surface water samples from all of the lakes to determine the stimulatory effect of nitrogen and/or phosphorus on algal growth. This special examination was performed on three successive weekly surface water samples. The samples were spiked with either sodium nitrate at a concentration level of 2.5 mg/l as N, or monobasic potassium phosphate at 0.5 mg/l as P or both. A control was also run. The results are shown in table 56. The dissolved orthophosphorus concentrations in the water samples originally present are also listed. The means of all three experimental runs are shown in table 57.

The dissolved orthophosphorus concentrations and the biomass values in the control samples were low for all three test runs. This is mainly because the nutrients in solution have already been utilized by the active standing crop of algae leaving the lake surface waters basically deficient in nutrients. For the assays, the samples were filtered initially with 0.45 μm filter papers leaving the test media nutrient poor. The addition of either nitrogen or phosphorus resulted in only a very slight increase in some cases and a reduction of algal biomass in a few cases. The differences in mean values are so small that they could have arisen either from experimental procedures or from the marginal stimulatory or inhibitory effects of the added nitrogen and phosphorus (table 57). However, when both nitrogen and phosphorus were added to the water samples, the algal biomass increased several orders of magnitude.

The effort to delineate the effects of nitrogen and phosphorus clearly indicates that both these nutrients are essential to algal growth in the Chain. Lack of one of these nutrients

Table 56. Effects of Nitrogen and Phosphorus Additions on Algal Biomass

(in milligrams per liter)

Lake	*Control of dissolved orthophosphorus*	*Control*	*Nitrogen added*	*Phosphorus added*	*Nitrogen and phosphorus added*
October 6, 1975					
Catherine	0.04	8.6	15.2	12.1	59.6
Channel	0.15	8.6	49.5	6.8	58.6
Marie (east)	0.02	5.4	6.8	1.1	47.4
Marie (west)	0.02	3.2	6.1	1.1	47.5
Bluff	0.03	4.1	8.9	6.7	58.5
Petite	0.03	1.1	6.8	4.2	48.5
Fox Lake (Stanton Bay)	0.01	1.1	1.1	1.1	41.4
Fox Lake (main)	0.04	1.3	14.9	3.5	45.4
Fox Lake (Mineola Bay)	0.02	6.6	16.1	8.1	38.4
Nippersink	0.02	3.5	9.1	10.1	49.9
Pistakee (main)	0.01	7.4	8.7	9.6	57.5
Pistakee Bay	0.01	5.5	9.7	5.4	53.5
Grass Lake (south)	0.00	3.3	1.3	6.6	54.5
Grass Lake (north)	0.00	1.1	2.4	4.5	48.5
Cedar Lake	0.00	3.5	5.5	8.7	52.7
October 13, 1975					
Catherine	0.02	13.1	15.2	16.2	63.6
Channel	0.00	9.7	10.1	8.9	58.6
Marie (east)	0.00	6.8	15.1	14.1	64.6
Marie (west)	0.00	7.7	8.1	9.1	63.7
Bluff	0.00	9.7	7.1	10.1	61.5
Petite	0.00	7.6	7.6	9.1	53.6
Fox Lake (Stanton Bay)	0.00	6.6	12.1	7.6	54.6
Fox Lake (main)	0.01	5.6	21.2	8.1	56.4
Fox Lake (Mineola Bay)	0.03	9.5	27.2	7.1	54.6
Nippersink	0.03	4.6	13.2	9.8	58.6
Pistakee (main)	0.00	12.1	15.2	10.2	61.6
Pistakee Bay	0.00	9.1	11.1	10.1	51.6
Grass Lake (south)	0.01	12.2	11.2	10.9	56.6
Grass Lake (north)	0.01	13.1	14.1	12.1	55.5
October 20, 1975					
Catherine	0.02	6.2	16.1	23.2	55.7
Channel	0.01	9.1	9.1	10.1	54.6
Marie (east)	0.01	13.1	19.1	12.1	66.6
Marie (west)	0.01	8.8	14.1	6.9	49.6
Bluff	0.01	8.9	17.1	7.9	62.7
Petite	0.01	9.7	9.1	7.1	58.6
Fox Lake (Stanton Bay)	0.01	3.1	1.1	1.5	47.3
Fox Lake (main)	0.01	2.1	1.4	5.6	37.3
Fox Lake (Mineola Bay)	0.01	3.2	4.6	1.7	60.6
Nippersink	0.00	1.2	6.7	7.7	35.4
Pistakee (main)	0.01	9.1	17.2	16.8	69.7
Pistakee Bay	0.01	7.1	7.9	7.8	16.2
Grass (south)	0.01	11.7	12.1	4.5	17.7
Grass (north)	0.01	5.5	10.1	8.7	44.4
Cedar Lake	0.01	3.2	1.4	1.1	54.6

Note: Nitrogen added was in the form $NaNO_3$ (sodium nitrate) with 2.5 mg/l of nitrogen; phosphorus added was from solution K_2HPO_4 with 0.5 mg/l of phosphorus.

Table 57. Effects of Nitrogen and Phosphorus Addition on Algal Biomass (Mean of Three Experimental Runs)

(in milligrams per liter)

Lake	*Control of dissolved orthophosphorus*	*Control*	*Nitrogen added*	*Phosphorus added*	*Nitrogen and phosphorus added*
Catherine	0.03	9.3	15.5	17.2	59.6
Channel	0.05	9.1	22.9	8.6	57.3
Marie (east)	0.01	8.4	13.7	9.1	59.5
Marie (west)	0.01	6.6	9.4	5.7	53.6
Bluff	0.01	7.6	11.0	8.3	60.9
Petite	0.01	6.1	7.8	6.8	53.6
Fox Lake (Stanton Bay)	0.01	3.6	4.8	3.4	47.8
Fox Lake (main)	0.02	3.0	12.5	5.7	46.4
Fox Lake (Mineola Bay)	0.02	6.4	16.0	5.6	51.2
Nippersink	0.02	3.1	9.7	9.2	48.0
Pistakee (main)	0.01	9.5	11.0	12.2	62.9
Pistakee Bay	0.01	7.2	9.6	7.8	40.4
Grass (south)	0.01	9.1	8.2	7.3	42.9
Grass (north)	0.01	6.3	8.9	8.4	49.5
Cedar	0.01	3.4	3.5	4.9	53.7

Note: Nitrogen added was in the form $NaNO_3$ (sodium nitrate) with 2.5 mg/l of nitrogen; phosphorus added was from solution K_2HPO_4 with 0.5 mg/l of phosphorus.

in the water effectively curbs algal growth. Blue-green algal species have been known to be capable of fixing nitrogen from the atmosphere and are capable of thriving at a much lower nitrogen concentration in water than is required by diatoms and greens. Consequently, controlling the availability of phosphorus in the waters at both external and internal sources appears to be an effective procedure for controlling algal blooms in the Chain of Lakes system. There is an abundance of evidence in the technical literature to indicate that algal blooms and phosphorus concentrations in lakes are directly related (Bartsch, 1972; Bachmann and Jones, 1974). Bartsch concluded that limiting phosphorus availability in lakes is the single most important and necessary step to be taken in eutrophication control.

Remedial Measures

Two recent publications (Dunst et al., 1974; U.S. Environmental Protection Agency, 1973) provide excellent summaries of remedial measures which have been applied in lake rehabilitation programs. The information given below has been taken mainly from these two sources.

Measures which may be effective in the restoration and enhancement of the quality of lakes can be considered under the following two major categories:

Limiting nutrient influx

- Point source nutrient removal and control
- Nutrient diversion
- Control of nonpoint sources of nutrients

In-lake treatment and control measures

- Dredging
- Nutrient inactivation/precipitation
- Dilution and dispersion

- Lake bottom sealing
- Artificial destratification and hypolimnetic aeration
- Sediment exposure and desiccation
- Harvesting nuisance organisms
- Chemical control of nuisance organisms
- Biological control of nuisance organisms

The lake restoration techniques mentioned here have been employed either alone or in combination with one or more of the other techniques in lake restoration schemes. The U.S. Environmental Protection Agency (1973) report states:

> "The approach to the rehabilitation of degraded lakes is two-fold: (1) by restricting the input of undesirable materials and (2) by providing in-lake treatment for the removal or inactivation of undesirable materials. Obviously the only means of maintaining the quality of a lake once desired conditions are achieved, is by rigidly restricting the input of undesirable materials. In some lakes reducing or eliminating the primary sources of waste loading is the only restorative measure needed to achieve the desired level of improvement. Once the source of pollution is abated, natural flushing and dilution with uncontaminated water may result in substantial improvements in the quality of the lake. However, in many lakes, particularly in hypereutrophic lakes with slow flushing rates, in-lake treatment schemes may also be required before significant improvements will be realized. In-lake treatment alone, without controlling pollutional inflows, cannot be termed a restorative measure as only the symptoms or products of eutrophication and pollution are treated and no permanent improvements in quality are achieved. In any lake restoration program, controlling the input of undesirable materials is the initial step towards permanent lake rehabilitation; all other remedial measures are supplementary to this action."

Limiting Nutrient Influx

Limiting nutrient influx and diversion have been widely practiced as lake restoration schemes in the United States. Lake Tahoe is a striking example where advanced waste treatment for nutrients removal, removal of both nitrogen and phosphorus, and diversion of treated effluents were practiced even before any problems of eutrophication began to appear in the lake. Lake Washington near Seattle, prior to 1963, received heavy nutrient loading from 11 sewage treatment plants discharging directly into the lake. The lake deteriorated to a state of eutrophy. A series of steps were instituted by the municipality of metropolitan Seattle to divert sewage from Lake Washington. Complete diversion was achieved by 1968. Phosphorus was identified as the main element causing eutrophic conditions in the lake. With the reduction of phosphorus by about 80 percent of the initial levels, algal growth in the lakes decreased, secchi disc readings improved, and water quality improvement has been dramatic.

Madison lakes in Wisconsin have a long history of algal problems. Initially Lake Monona, the second of the series of four lakes on the Yahara River, received the sewage from the city of Madison. As a consequence, algal growths became prolific and a regular program of treatment with copper sulfate was established in 1925. In 1928, treated effluent was diverted to the Yahara River downstream from Lake Monona. Since the diversion, the amount of copper sulfate needed to prevent algal blooms decreased significantly. A change in species composition which did not form surface scums resulted in diminished copper sulfate application. Shortly after the effluent was moved downstream from Lake Monona, the symptoms of eutrophication in the lower two lakes began to intensify. Finally in 1958, the treated effluent from Madison was diverted to the Yahara River downstream from all the lakes. Since diversion, the conditions of the lakes have been reported to have improved (Sonzogni et al., 1975).

Nonpoint sources of pollution, which are incidental to land uses throughout the drainage basin of a lake, are a significant cause of lake degradation. Efforts to limit nutrients and sediment inputs from lands within drainage basins, for lake protection as well as rehabilitation, have followed two general lines: 1) structural and land treatment measures to intercept nutrients and sediments before they reach water bodies; and 2) regulatory approaches, particularly land use controls to restrict uses with direct or indirect pollution potential. Soil conservation practices like contour farming, grassed waterways, crop residue management, feedlot waste management, etc., fall into the first category. Regulations on fertilizer application shoreline protection statutes, etc., fall into the latter category.

In-Lake Treatment and Control Measures

Even though all of the in-lake treatment and control measures listed earlier are not directly applicable to the Fox Chain of Lakes, a brief description of these rehabilitation schemes is outlined here. Along with advantages and disadvantages, a few case studies where these techniques were employed are cited. This information should aid in developing a rational management scheme for the Fox Chain of Lakes.

Dredging. Dredging is considered a feasible method of nutrient control for preventing the recycling of nutrients from lake bottoms (U.S. Environmental Protection Agency, 1973; Pierce, 1970). As indicated earlier, highly eutrophic lakes receive large amounts of autochthonous materials resulting from massive algal growths. Much of the organic material entering the hypolimnetic zones will not degrade rapidly because of the lack of oxygen. Dredging of the accumulated organic matter has thus been proposed as a remedial technique.

Investigation of 49 lakes and ponds led Pierce (1970) to conclude that very little information is available as to whether dredging improves or damages a lake's aquatic environment. Most of the dredging reported in the literature is for maintaining navigational channels or for increasing the storage of water supply lakes. Churchill et al. (1975) reported that with limited dredging in Lake Herman, South Dakota, over a period of three years, significant amounts of nutrient were removed. Wilbur (1974) reported selective dredging in the littoral zones of two lakes in Florida where an organic muck bottom was converted to a sandy bottom which supported desirable benthic populations. The dredging effort was undertaken primarily to reverse the loss of a productive lake bottom and thus improve the gamefish population.

Lake bottom dredging experience in Lake Tummen in Sweden (143 acres, 6 feet mean depth), where the technique was adopted with the specific purpose of arresting the eutrophic trend in the lake, is worth mentioning here. The upper 2 feet of nutrient rich sediments were dredged. The phosphorus concentration of the lake water in the year following dredging was about 0.1 mg/l compared with values as high as 1.0 mg/l in the predredging period. Dissolved oxygen concentrations remained well above critical levels compared with total depletion in earlier years. Green algae replaced blue-green algae to a large extent, although phytoplankton production was still high. A general improvement in water quality has been observed (Dunst et al., 1974).

Dredging was also employed in Crystal Lake in Minnesota. This lake has a surface area of about 400 acres and a mean depth of about 15 feet. The effort was undertaken to minimize winter fish kills and reduce algal production. It is reported that no noticeable improvement in lake water quality occurred but further lake deterioration has been arrested (Dunst et al., 1974).

Among the several disadvantages cited for dredging, the significant ones are:

1) Dredging operations are expensive
2) The operation may release nutrients from the sediments into the overlying waters
3) The nutrient content of the sediments may remain high at considerable depth, thus making it impossible to reach a low nutrient level in sediment
4) Turbidity resulting from the process may persist for a considerable time during and following operations
5) Satisfactory disposal of the spoils may be very expensive

There are several methods available for dredging sediments from the lake bottom. These methods can be classified as either mechanical dredging or hydraulic dredging. Pierce (1970) has presented a detailed discussion on the various types of equipment and the methods employed in lake dredging operations. On the basis of his investigation of 49 lakes, Pierce reported that anticipated excavation costs for an average project (50,000 cubic yards of excavation or more) would be from 45 to 75 cents per cubic yard (¢/cu yd), if done on a contract basis. As the size of the project increases, the unit cost will decrease to the low side of the range. The U.S. Environmental Protection Agency (1973) has reported dredging costs of 38 and 47¢/cu yd in Wisconsin and Iowa lakes. Roberts (1975) reported a dredging cost of 78¢/cu yd for Lake Oakland in Illinois.

Nutrient Inactivation/Precipitation. This technique is viewed as a method of hastening the recovery of a lake from a eutrophic condition. The purposes of this in-lake treatment are:

1) To change the form of a nutrient to make it unavailable to plants
2) To remove the nutrient from the photic zone
3) To prevent release or recycling of potentially available nutrients within the lake

In-lake nutrient inactivation techniques have been primarily directed toward phosphorus. Inactivants which have received the most attention are aluminum, iron, and calcium salts. Of these three, aluminum appears to be the only one applicable to lakes in Illinois. Calcium is ineffective in removing phosphorus at pH values less than 9. Ferric iron is undesirable because of its tendency to be reduced to the soluble state under anaerobic conditions. Peterson et al. (1974a) reported that compounds of lanthanium, zirconium, tungsten, and titanium used in laboratory tests were capable of removing phosphorus from lake water. Other materials being used or considered as coagulants include ion exchange resins, polyelectrolytes, fly ash, powdered cement, and clay.

Horseshoe Lake (surface area 22 acres; maximum depth of 55 feet) in east-central Wisconsin was treated in May 1970 for nutrient inactivation. As reported by Peterson et al. (1973), slurried alum was applied to the top 2 feet of water at a concentration level of about 18 mg/l (200 mg/l alum). The results of the treatment were: 1) a decrease in total phosphorus in the lake water during the summer following treatment; 2) no large increase in total phosphorus in the hypolimnion during the following two summer stratifications; 3) some increase in the transparency of the water during the summer following treatment; 4) a short-term decrease in color; 5) an absence of the nuisance planktonic algal blooms that had been common in previous years; 6) marked improvement in dissolved oxygen conditions, particularly during the following winters; and 7) no observations of adverse ecological consequences.

Lake Langsjon (surface area of 86.5 acres; maximum depth of about 10 feet) located in Stockholm, Sweden, was treated with 33.5 tons of granulated aluminum sulfate (Jernelov, 1970). The immediate results of alum treatment were an increase in depth of secchi disc readings and a reduction in dissolved orthophosphorus from 60 to 5 μg/l. The flocculated aluminum hydroxide covered the bottom with a light grey layer of 0.5- to 1-inch thick. Better oxygen conditions prevailed during the winter of 1968–1969 and no release of phosphorus from the sediments was noted though conditions were anaerobic.

Shannon et al. (1974) reported the results of alum treatment (dosage 2.5 mg/l as Al) of the Fourth Welland Canal in Canada. Alum treatment was found to be effective in controlling algal mass. The zooplankton population was not adversely affected. The cost of treating the Fourth Welland Canal amounted to approximately $90 per acre of water surface.

The major drawbacks cited against this method of lake renovation are:

- The relatively high cost of treatment, particularly the manpower costs
- Possible toxic effects from the introduction of an excess of a metal
- Adverse biological effects from the formation of floc (The floc could conceivably suffocate aquatic organisms, as well as interfere with the benthic ecology.)
- Lack of information on the effective duration of the treatment (Continued inflow of nutrients and bacteriologic and benthic organism activity could influence the longevity of treatment effects.)

Dilution and Dispersion. This technique has been attempted to alleviate excessive algal growths and associated problems by reducing nutrient levels within the lake. This is accomplished by the replacement of nutrient rich waters with nutrient deficient waters and the washout of phytoplankton. Nutrient dilution has been attempted by two procedures: 1) pumping water out of the lake and permitting increased inflow of nutrient poor groundwater; and 2) routing additional quantities of nutrient poor surface waters into the lake.

The first procedure was used in Snake Lake in Wisconsin (Peterson et al., 1974b). Nutrient levels were initially reduced significantly and duckweed blooms were eliminated. Leaching from nutrient rich sediments limited the effectiveness in this particular case.

The second procedure has been tried in several places. Two of the most successful experiments were at Green Lake in Washington, and Buffalo Pound Lake in Canada (Dunst et al., 1974). After 5 years of flushing at rates of 3.5 times per year or less, and after some initial dredging in Green Lake, the blue-green algal standing crop was suppressed and there was a shift in dominance with the elimination of *Aphanizomenon.* Subnuisance levels of blue-green algae were attained after 4 years in Buffalo Pound Lake.

Lake Bottom Sealing. In lieu of physical removal of organic rich sediments, sediment sealing may provide control at less cost. Covering of bottom sediments with sheeting material (plastic, rubber, etc.) or particulate material (sand, clay, fly ash, etc.) can prevent the exchange of nutrients from the sediments to the overlying waters either by forming a physical barrier or by increasing the capacity of surface sediments to hold nutrients.

The problem encountered when covering sediments is the ballooning of the sheeting, or rupturing of the seal due to gas production in the underlying sediments. Sand and other materials of large size tend to sink below flocculant sediments. Clay, fly ash, bentonite, and other similar materials appear to be best suited for sediment covering.

Covering of sediment to improve lake conditions has been done at Marion Millpond, Wisconsin (University of Wisconsin, 1974). The 110-acre lake was treated in 1971 by the scraping of overburden to a sand substrate, providing a sand blanket, and covering a part of the lake sediments with black plastic sheeting anchored with sand and gravel.

Fly ash in combination with lime has been used for phosphorus removal and sediment covering in Lake Charles East in northeastern Indiana (Higgins et al., 1975) as a demonstration project. Treatment of a 7-acre portion of the lake required 2000 tons of fly ash and 24 tons of lime at an estimated cost of $22,000. To prevent phosphorus breakthrough for an extended period, a 2-inch layer of fly ash seal was found necessary.

Artificial Destratification and Hypolimnetic Aeration. Artificial destratification and hypolimnetic aeration is a process by which the lake waters are oxygenated and circulated. This is accomplished by either mechanical water pumps or by compressed air released at the lake bottom. In the case of compressed air mixing, vertical water currents are generated as the bubbles rise to the surface. The colder and denser bottom water mixes with warmer surface water, then sinks to a level of equal density and spreads horizontally. Oxygen is added to the water directly from the compressed air as well as by contact with the atmosphere. As the mixing process continues, complete circulation is achieved and the lake approaches uniform temperature and dissolved oxygen conditions from the surface to the bottom. The whole water mass becomes inhabitable by lake biota.

In contrast to total aeration, several types of aeration devices have been designed to oxygenate the hypolimnetic waters without disrupting thermal stratification. Typically, the aerator consists of a large diameter pipe which extends from the lake bottom to a few feet above the water surface. Water inlet ports are located near the bottom of the pipe and outlet ports are located below the thermocline. The bottom water is airlifted up the vertical tube. The rising bubbles are vented to the atmosphere and the water is returned to the hypolimnion.

The advantages of artificial destratification in eutrophic lakes are:

- With increased oxygen levels in the hypolimnion, there is a reduction in the anaerobic release of nutrients from the bottom sediments
- Oxidation of reduced organic and inorganic materials occurs in the water (This is particularly advantageous when the lakes serve as a raw water source, because taste, odor, and color problems caused by iron, manganese, and/or hydrogen sulfide are eliminated or at least minimized.)
- The range of benthic populations is extended to the profundal region which was once anaerobic (An increase in the number of fish and a shift to more favorable species can result from the greater availability of food organisms.)
- Favorable changes in algal populations occur with a decrease in undesirable blue-green species (This is a result of the lowering of water temperature of the algae between the euphotic and aphotic zones; however, there is no reduction in the productivity of the lake.)
- Evaporation rates are reduced in summer with the reduction in surface water temperatures
- Artificial destratification often results in increased water clarity
- Winter fish kills may be prevented by maintaining sufficient oxygen levels under ice

The disadvantages of artificial destratification include:

- Increased heat budget in the lake
- Aeration may temporarily increase water turbidity due to the resuspension of bottom sediments
- In most investigations artificial destratification resulted in a reduction in blue-green algae, but in other instances there had been no observable effect on blue-green algae
- The artificial destratification may induce foaming
- The oxygen demand of resuspended anaerobic mud may result in a decrease in oxygen concentrations, temporarily at least, that may kill fish

Kezar Lake in Sutton, New Hampshire, which is a recreational lake (surface area 182 acres; maximum depth 27 feet) began to experience severe and objectionable blue-green algal blooms in 1963 (New England Regional Commission 1971, 1973a, 1973b). Control of algal blooms with copper sulfate proved ineffective. Artificial destratification by diffused aeration was tried as a means of alleviating the aesthetic problems created by the algal blooms. Subsequently, a series of tertiary waste treatment steps, including phosphorus removal, were instituted and artificial destratification was continued. The lake restoration scheme was deemed successful as aeration achieved the stated objective of increased secchi disc transparencies of 4 feet or more during summer months. The lake was isothermal and the dissolved oxygen was homogeneous throughout the water column. There was a rapid decrease in the dominant blue-green algal species of *Aphanizomenon.*

Hypolimnetic aeration was applied continuously to Hemlock Lake in Michigan from June 14 to September 7, 1970 (Fast et al., 1973). Hemlock Lake is a eutrophic lake with a surface area of 6 acres and a maximum depth of 61 feet. Before artificial aeration, hypolimnion oxygen concentrations were typically zero below thermocline. Phytoplankton populations usually limited the secchi disc transparencies. After initiating aeration, there was an initial increase in phytoplankton cell numbers. However, the standing crop decreased subsequently from 30,000 cells/ml to less than 500 cells/ml. Concomitantly, secchi disc measurements increased to over 30 feet, the deepest ever recorded for the lake. Following aeration, zooplankton inhabited the deeper lake waters and their numbers increased until predation stress by fish caused zooplankton numbers to decline. The total number of zoobenthos increased although the biomass remained the same.

The U.S. Environmental Protection Agency (1973) compiled cost data for artificial destratification. The minimum, mean, and maximum initial costs (purchase and installation) were reported as $0.05, $4.39, and $19.70 per acre-foot, respectively. It was reported that 90 percent of the respondents utilized compressed air devices for aeration, and 4 percent used mechanical pumps. One-third of the respondents employed continuous operation, one-third continuous during the summer, and one-third intermittent operation. The operating costs varied from a maximum of $4.62 to a minimum of $0.003/acre-foot/year, with a mean of $0.94/acre-foot/year. The initial cost and the operating cost per unit volume declined as the volume of the reservoir increased. No clear trend emerged with regard to the costs of the type of equipment or the operating schedule employed.

Sediment Exposure and Desiccation. Water level manipulation has been employed as a mechanism for enhancing the quality of certain lakes and reservoirs. The exposure of lake bottom mud to the atmosphere reduces sediment oxygen demand and increases the oxidation state of the mud surface. This procedure may retard the movement of nutrients from the sediments to the overlying water when flooded once again. Sediment exposure can also curb sediment nutrient release by physically stabilizing the upper flocculant zone of the sediments. Lake drawdown has been investigated as a control measure for submerged rooted aquatic vegetation, and as a mechanism for lake deepening through sediment consolidation. Because this method does not hold any promise in the Fox Chain of Lakes, it is not discussed further.

Harvesting Nuisance Organisms. Harvesting of nuisance organisms is limited to macrophytes and some undesirable fish. Technical difficulties have precluded in-lake harvesting of algal cells. The technique has been advocated as a practical means of accelerating the nutrient outflow from lake systems. However, this technique alone is deemed inadequate for lowering nutrient supplies in lakes receiving cultural enrichment (Neel et al., 1973). Removal of weeds and fish may hasten nutrient depletion after elimination of extraneous nutrient influx.

Mechanical control deals with harvesting and removal of aquatic plants from the water.

Mechanical removal of plants allows immediate use of the harvested area and the plants removed from the water are not available to deplete dissolved oxygen resources and release nutrients for new plant growth. According to a survey of mechanical harvesting used in 32 locations in the upper Midwest, information on the acreage harvested, including the costs, was not reliable. The high initial investment in machinery was the most serious obstacle to implementing a management program. Costs for weed control by mechanical harvesting were reported to vary from about $15 to $75 per acre.

Chemical Control of Nuisance Organisms. Nuisance algal blooms, dense growth of macrophytes, and unbalanced fish populations often restrict various recreational and domestic uses of surface waters. Chemical treatment has been most widely used as a treatment method. Chemical treatment has the greatest utility and justification in highly eutrophic lakes in which the nutrient supply cannot be effectively controlled or in which nutrient input control measures are envisaged sometime in the future. Based on the intent, chemical controls can be divided into three categories: 1) algicides, 2) herbicides, and 3) piscicides. Because algal blooms are the most severe problem in the Fox Chain of Lakes, only algicides will be dealt with here.

Copper sulfate is probably the most widely used chemical for control of blue-green algae, taste and odor producing algae, and some filter clogging algae. Over 10,000 tons of copper sulfate are used for this purpose each year in this country at concentrations ranging from less than 0.5 mg/l to more than 10.0 mg/l (Fitzgerald, 1971). The amounts of oxygen, organic matter, and alkalinity in the water determine the dosages required for effective plankton control (Fitzgerald, 1971; Mackenthun, 1969; and Mulligan, 1969). For waters with alkalinity greater than 40 mg/l, copper sulfate at a rate of 1 mg/l for the upper 2 feet of water regardless of actual depth has been widely used (Mackenthun, 1969). On an acreage basis, the concentration would amount to 5.4 lbs/surface acre. For lakes with alkalinity less than 40 mg/l, a concentration of 0.3 mg/l of copper sulfate amounting to 0.9 lbs/acre has been suggested. The difference is mainly due to the fact that the effectiveness of copper sulfate is reduced in high alkalinity waters because of the formation of an insoluble precipitate of copper basic carbonate. Chelated copper sulfate (cutrine), which does not precipitate as readily as copper sulfate, has been employed successfully in controlling noxious algal blooms (Dunst et al., 1974).

Copper sulfate has a low mammalian toxicity, is inexpensive, and is effective in controlling a wide range of plankton algae. However, instances of fish kills have been reported soon after copper sulfate applications. These were generally traced to improper application and excessive dosage rates. The toxic effect of copper sulfate on plants is caused by the inactivation of enzymes and precipitation of proteins by the divalent ion Cu^{2+}.

Copper sulfate may be applied in a variety of ways: bag dragging, dry feeding behind power boats, liquid spray, or airplane application of either dry or wet material. Application by blowing the chemical rather than by slurry has also been employed (Mackenthun, 1969). The advantage of the blower-type machine is the ability to treat a large surface area rapidly with a light dosing of material. Use of blower-type machines is dependent upon the wind for distribution of the chemical. However, there is always some loss of copper sulfate dust that is carried by wind to the shore of the lake. Helicopters have also been used in chemical distribution. The East Bay Water Company, Oakland, California, found that a more efficient treatment could be attained with a helicopter (Mackenthun, 1969).

Chemical algal control measures should be undertaken before the maximum development of algal blooms. Mackenthun (1969) suggests that it is a good practice to subdivide the total area into sections and control the nuisance in one section followed by treatment of other sections at intervals of 7 to 10 days. This procedure will ensure that sufficient dissolved oxygen is present to satisfy the demands of the decomposing algae.

The frequency of copper sulfate application varies from a single annual application to monthly applications during spring and summer. The continuous feed of copper sulfate to the inlet of a reservoir has also been reported (Muchmore, 1973).

The toxicity of copper sulfate toward humans presents no problem at the concentration levels normally used in lakes and reservoirs. Of concern, in long-term treatment of water supplies with copper sulfate, is the potential of accumulating harmful amounts of copper in the bottom sediments (Muchmore, 1973). The copper added as copper sulfate will end up in bottom sediments. Muchmore reports that a study of a group of Wisconsin lakes where copper in bottom muds of reservoirs that had been routinely treated with copper sulfate was considerably lower in concentration than the 9000 ppm (dry basis) they found necessary to affect bottom dwelling organisms. No difference in the diversity of benthal populations could be attributed to the presence of copper.

Cost per acre for chemicals and application have been reported by the Water Survey as about $2.00 in 1966. Dunst et al. (1974) reported that, for Mascoma Lake (1110 acres) in New Hampshire, the cost of application of copper sulfate including chemical cost amounted to about $2.60 per acre. The Southeastern Wisconsin Regional Planning Commission (1969) used the following cost figures: cost of chemicals (copper sulfate) at $1 per acre treated; a boat or barge and spraying apparatus at an initial cost of $1250; and operation and maintenance costs of $50 per day.

Other algicides of some use are the rosin amines, triazine derivatives, mixture of copper sulfate and silver nitrate, quarternary ammonium compounds, organic acids, aldehydes, ketones, etc. Prows and McIlhenny (1973, 1974) reported after examining more than 10,000 compounds that p-chlorophenyl-2-thienyl iodonium chloride is an effective chemical for algal control. Based on laboratory tests and limited field evaluations, the authors concluded that the compound is safe to applicators, fish, and other higher aquatic plants and animals; it has a fairly rapid degradation pattern under open atmospheric conditions with a half life of 1 to 2 days; and it exhibits a high degree of specificity to nuisance algae, particularly *Anabaena, Microcystis, Aphanizomenon,* and *Oscillatoria.* It must be pointed out that none of these algicides has been used as extensively as copper sulfate.

Biological Control of Nuisance Organisms. This approach encompasses the introduction or promotion of organisms that are inimical to the target organisms. Dense growths of aquatic macrophytes were found to inhibit the growth of phytoplankton, both by direct competition for nutrients and by shading. One of the natural ways in which algal populations are kept under control is through predation by zooplankton and fish species. Effective grazing by *Daphnia* and related zooplankton on phytoplankton populations in a mesotrophic lake has been reported (U.S. Environmental Protection Agency, 1973). Dunst et al. (1974) reported that suitable plankton feeding fish species are *Tilapia mossambica,* and its allies, *Hypophthalmichthys molitriz* and *Mugil cephalus.*

Dunst et al. (1974) reported about the only deliberate in-lake treatment to control blue-green algae by the use of virus. Blue-green algal scums were apparently dissolved as a result of spraying cyanophages on the surface of a lake in the U.S.S.R. Evaluation of biological controls has been limited, with much of the testing conducted in laboratory and experimental ponds. In general, biological control measures have met with only very limited success.

Water Quality Management Plan

The lakes of the Fox Chain have a common glacial origin, though their shapes, sizes, depths, and volumes are quite different. Control techniques must be equally diverse. There is, however, a common thread inherent in all water quality restoration schemes for lakes. It is the fundamental need to minimize the input of critical nutrients to the lake system.

Carbon, nitrogen, phosphorus, sulfur, iron, silica, and other elements in trace amounts are essential for algal growth. The concensus among limnologists is that nitrogen and phosphorus are the critical elements. As reported here earlier, both of these elements are growth limiting for the waters of the Chain. To minimize one of the elements will have the effect of minimizing both. The techniques for removing phosphorus are more advanced, predictable, and effective than those thus far developed for removing nitrogen. It makes sense therefore to undertake a major effort to reduce the phosphorus burden from controllable sources now being imposed upon the lake system.

As goals for phosphorus reduction, the findings of Sawyer (1952) and Vollenweider (1968) are useful. Sawyer, as mentioned earlier, concluded that nuisance algal blooms are likely to develop in lakes during summer months when concentrations of inorganic nitrogen and inorganic phosphorus are in excess of 0.3 and 0.01 mg/l, respectively. Vollenweider concluded that loading rates of biochemically active nitrogen and phosphorus in excess of 2.0 and 0.13 $g/m^2/yr$, respectively, are critical. The attainment of these goals in the Fox Chain of Lakes is unlikely. To do so would require the estimated total phosphorus load of 10.4 $g/m^2/yr$ (1675 lbs/day) now applied to the lake system to be reduced to about 0.13 $g/m^2/yr$ (21 lbs/day).

About 1190 lbs/day of total phosphorus, an estimated 69 percent of the total, originates in Wisconsin. The Southeastern Wisconsin Regional Planning Commission envisages a water quality management plan for the Fox River basin in Wisconsin. Phosphorus removal facilities for municipal and industrial waste discharges are anticipated. Control measures applicable to soil conservation practices for the management of nonpoint sources are contemplated. Any long-term restoration scheme instituted in Illinois without coordinated activity in Wisconsin can have, at best, only temporary and marginal impact in remedying eutrophic conditions in the lakes.

Of the estimated 485 lbs/day total phosphorus emanating within Illinois (excluding precipitation as a source) about 295 lbs/day comes from point sources. Of the 190 lbs/day derived from nonpoint sources, about 55 lbs/day comes from malfunctioning septic tank systems.

The complete removal of phosphorus from the lake system now imposed by Antioch, Lake Villa, Round Lake Sanitary District, and Fox Lake would provide a reduction of 130 lbs/day. A collection system for the septic tank areas would remove an additional 55 lbs/day.

The upgrading of the treatment facilities at Hebron, Richmond, and Woodstock would eliminate phosphorus emission from the Hebron facility, and would provide about a 95 percent reduction at the other two sites. This would mean an overall reduction of an additional 145 lbs/day total phosphorus.

An effective wastewater management scheme founded on current technology could reduce the point sources of phosphorus in Illinois from 295 to 20 lbs/day, as well as reduce the nonpoint sources of 190 to 135 lbs/day. This is an overall reduction of about 93 percent for the point source load and about 29 percent for the nonpoint source load.

This demonstrates the importance of instituting a program for controlling nonpoint sources on the watershed within Illinois. About 115 of the 135 lbs/day of phosphorus comes into the lake system by way of Nippersink and Squaw Creeks. The remedial measures required for nonpoint source reductions on these two streams would differ. The watershed of Nippersink Creek is principally rural; the Squaw Creek watershed is principally urban.

Another complicating factor is that Wonder Lake and Long Lake intercept Nippersink and Squaw Creeks, respectively, before the streams discharge into the Fox Chain system. Both of the lakes have been classified by the U.S. Environmental Protection Agency (1975b and 1975c) as highly eutrophic. The influence of these lakes is significant to the phosphorus transport of their respective outlet streams.

Pistakee Bay and the upper lakes in the Fox Chain system (Catherine, Channel, Marie, Bluff and Petite) experience total oxygen depletion below the thermocline during summer months because of their greater depths. The dominant algal species in these lakes are the scum forming blue-greens. Also the benthic population in these lakes is sparse and tolerant of extremely low oxygen concentrations. Destratification and circulation in these lakes is desirable. Oxygenation of the hypolimnetic waters will likely produce a shift in the dominant algal species from the blue-greens to the less objectionable greens. The development of increased and desirable benthic populations, leading to increased fish population, can also be anticipated. The estimated initial and operating costs for destratification in these lakes by the use of air are shown in table 58. Average initial and operating costs of $4.39 and $0.94/acre-foot/yr were used in developing these costs. Destratification in these lakes should be undertaken as soon as practicable.

Table 58. Cost Estimates for Lake Destratification

(Cost estimates in dollars)

Lake	*Initial cost*	*Annual operating cost*
Catherine	10,800	2300
Channel	19,200	4100
Marie	20,800	4500
Bluff	4,200	900
Petite	5,600	1200
Pistakee Bay	10,800	2300

Note: Average initial and operating costs of $4.39 and $0.94 per acre-foot per year, respectively, were used to estimate costs

As pointed out earlier, the recycling of phosphorus from the organic rich bottom sediments in the deep lakes is a significant source with which to reckon. The rates of phosphorus release from sediments under aerobic conditions are substantially less than release rates under anaerobic conditions. The creation of aerobic conditions by hypolimnetic aeration will lessen the impact of bottom sediments as an influential source of phosphorus. There are claims that aeration will also reduce the volume of organically enriched sediments through means of oxidation.

Anoxic conditions did not develop in the waters of the shallow lakes like Fox, Grass, Nippersink, and Pistakee Lakes, except at the mud-water interfaces. An appropriate restoration scheme for these lakes is a combination of nutrient inactivation and chemical control. The predominant species of algae in Grass Lake are diatoms. Nuisance algal blooms have not developed in this lake. Other than being turbid the water quality of Grass Lake is not degraded and a program for water quality restoration is not justified at this time.

The other three shallow lakes (Fox, Nippersink, and Pistakee) need remedial measures. Because of the uncertainties involved in the response of lakes to chemical treatment, it is proposed that demonstration schemes be initiated before embarking on full-scale measures for these three lakes. On the basis of the results of the pilot schemes, an appropriate large-scale program can be devised.

Mineola and Stanton Bays in the Fox Lake appear to be suitable for the pilot investigations. These waters are fairly well isolated from the main lake and are of such size that extrapolation of results obtained in them will be meaningful and readily applicable to the rest of the shallow lakes.

Chemical control of algae using cutrine (chelated copper sulfate) is recommended for Mineola Bay which has an area of about 205 acres. The chemicals can be applied in about 5 hours. For six applications during the period of May through October, the cost for equipment, chemicals, and application amounts to about $3000.

Nutrient inactivation by alum precipitation is proposed for Stanton Bay. Because of the high powered, high speed boating activites in the lakes and the shallowness of the bay (3 feet average depth) aluminum floc may remain in suspension. The effectiveness and longevity of this treatment will have to be carefully monitored. The cost of treating 95 acres of Stanton Bay is estimated to be $8500.

Whether or not the use of hypolimnetic aeration will minimize the influence of the bottom muds on the overlying waters will have to await trials. The alternative is to physically remove the sediments by dredging. The estimated costs of dredging the pertinent lakes are shown in table 59. These costs are predicated on dredging bottom areas of the lakes. The areal extent of sediment removal is to be confined to that portion of the bottom muds designated as 'algal silt' in figure 2. The depth of dredging is to be limited to the top 2 feet of the sediments. Costs were developed from an average rate of $0.50 per cubic yard.

Table 59. Cost Estimates of Dredging Organic Sediments

Lake	*Area of proposed dredging (acres)*	*Cost ($)*
Catherine	70	113,000
Channel	180	291,000
Marie	215	347,000
Bluff	40	65,000
Petite	95	153,000
Pistakee Bay	60	97,000

Note: Dredging costs per acre were developed by use of an average rate of $0.50 per cubic yard

SUMMARY

The results of an extensive technical program conducted jointly by the Illinois State Water Survey and Geological Survey on the Fox Chain of Lakes are presented in this report. This effort has been directed toward ascertaining the causes of lake eutrophication and the means by which these causes may be halted, reversed, or at least minimized. Geographic, geologic, hydrological, physical, chemical, and biological characteristics of the Fox Chain of Lakes have been employed in identifying the causes of eutrophic conditions of the lakes. The trophic condition of the lakes is discussed as related to their limnological characteristics and nutrient budget. The nutrients responsible for the accelerated aging of the lakes are identified, and the sources of the nutrients and proportional contribution of each source are assessed. The salient features of this investigation are summarized here.

Only about 27 percent of the Fox Chain of Lakes drainage area as measured at Johnsburg lies within Illinois. The Chain's water surface area is approximately 6850 acres and the lakes have a mean depth of about 5.7 feet at the normal pool elevation 736.5 feet above msl.

In Illinois there are seven municipal waste treatment plants serving about 37,800 persons located within the watershed. The population equivalent served by septic tank-field disposal systems in the vicinity of the Fox Chain of Lakes is estimated to be 22,250. In Wisconsin, there are 12 sewage treatment plants serving about 64,050 persons (1966 population) in the watershed. The Northeastern Illinois Planning Commission and the Southeastern Wisconsin Regional Planning Commission have developed plans to upgrade the waste treatment facilities including phosphorus removal in their respective regions.

The Fox River and other tributaries to the Fox Chain of Lakes are typical of midwestern streams – high in alkalinity, hardness, and total dissolved solids. The nitrate load transported by the tributaries ranged in value from 4.05 lbs/ac/yr for Nippersink Creek to 1.68 lbs/ac/yr for Lily Lake Drain. Total phosphorus load transported varied from 3.24 lbs/ac/yr for Sequoit Creek to 0.20 lbs/ac/yr for Lily Lake Drain.

The deep upper lakes of the Chain develop distinct summer stratification. These lakes become totally anoxic below the thermoclines. Marked increases of ammonia, phosphorus, silica, and other end results of anaerobic decomposition of bottom sediments were in evidence. The shallow lakes exhibited homogeneous thermal profiles. However, the dissolved oxygen concentrations near the lake bottoms showed a marked drop that presumably was caused by the high rate of oxygen demands of the bottom sediments.

Lakes with concentrations of 0.3 mg/l of inorganic nitrogen and 0.01 mg/l of available phosphorus at the time of spring overturn have been reported to experience algal blooms. The mean concentrations of total phosphorus varied from 0.08 to 0.30 mg/l in surface water samples and from 0.27 to 0.87 mg/l in deep water samples. Algal assay procedures were carried out to determine the effect of additional nitrogen and phosphorus in the surface water samples of all the lakes. Nitrogen or phosphorus added alone did not have any stimulatory effect on algal growth, but when added together to the water samples, the algal growth potential exhibited nearly 7- to 10-fold increase compared with the unspiked water samples.

Tributaries, direct discharge of waste treatment plant effluent, septic tank systems in the vicinity of the lakes, and precipitation are the major sources of nutrients for the Fox Chain of Lakes. The total phosphorus and total nitrogen loading rates were, respectively, 10.3 and 86.0 g/m^2 /yr. The critical loading rates for lakes with mean depths less than 5

meters (16.4 feet) suggested in the literature, are 0.07 and 1.0 g/m² /yr, respectively, for phosphorus and nitrogen. The total phosphorus and total nitrogen loading from the Fox River alone was estimated as 7.1 and 65.0 g/m² /yr, respectively. About 26 percent of total nitrogen and 37 percent of total phosphorus transported to the lakes are retained within the lake system.

Approximately 69 percent of the external phosphorus input to the lakes is brought by the Fox River. Nippersink Creek accounts for 13 percent. Precipitation and the impact of malfunctioning septic tank disposal systems account for 3 percent, each, of the total phosphorus input.

The phosphorus reaching the lake waters from nonpoint sources within Illinois and the recycling of phosphorus from the organic rich bottom sediments to the overlying waters are each of sufficient magnitude to cause algal growth problems in the lakes.

Controlling the nutrient input to the lakes from all sources is of paramount importance for reversing the eutrophic trend in the Fox Chain. Several regional plans for nutrient reduction have been proposed for Illinois and Wisconsin. Counter-proposals have been offered. The time schedule for these plans are not clear cut and it is likely that several years will elapse before these schemes can be implemented. In the interim, it is proposed that Lake Catherine be destratified and results evaluated before this technique could be applied to other deep lakes in the system. Channel Lake could serve initially as a control. The total initial costs of equipment and accessories are estimated to be $10,800 and the annual operation costs are estimated to be $2300.

The control of phosphorus recycling from the organic rich sediments of deep lakes by dredging can await the results of destratification. The cost of dredging the top 2 feet of the sediments rich in organic content in the deep lakes is estimated to be $1,066,000.

Two pilot scale demonstration schemes are proposed in order to develop a reliable interim restoration scheme for the shallow lakes. The effects of the control of algal blooms by the application of chelated copper sulfate to the waters in Mineola Bay (Fox Lake) at a cost of about $3000 is recommended. Nutrient inactivation by the application of alum is recommended for Stanton Bay (Fox Lake).

Artificial destratification and the chemical controls proposed here are designed to offer some immediate relief from the consequences of eutrophication. The ultimate success in reversing the eutrophic trends in the Fox Chain of Lakes will depend on the drastic reduction of the nutrient loading to the lake system both from without and within the lake area.

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EXPLANATION

- ● Well penetrating bedrock
- ○ Well completed above bedrock
- —660— Contour interval 20 feet
  datum sea level
- ▲ Bedrock exposure
- — — — Preglacial St. Lawrence
  and Mississippi divide

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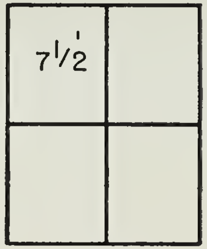

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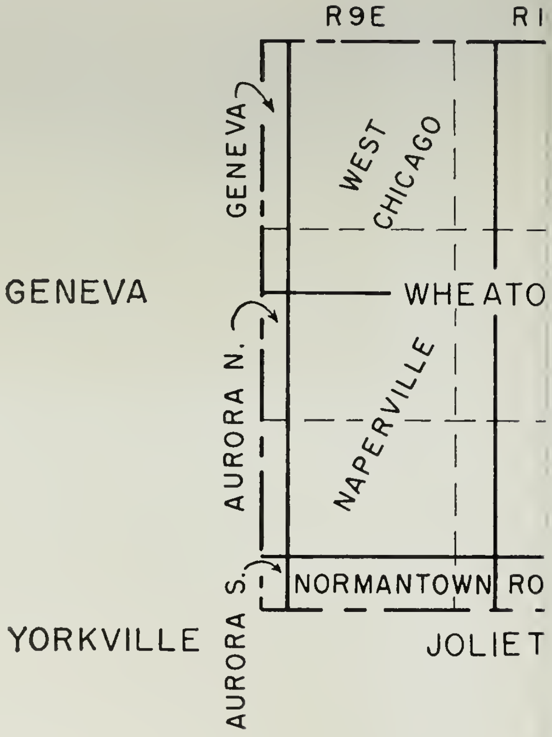

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MAPS OF DU P

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TOPOGRAPHY OF BEDROCK SURFA

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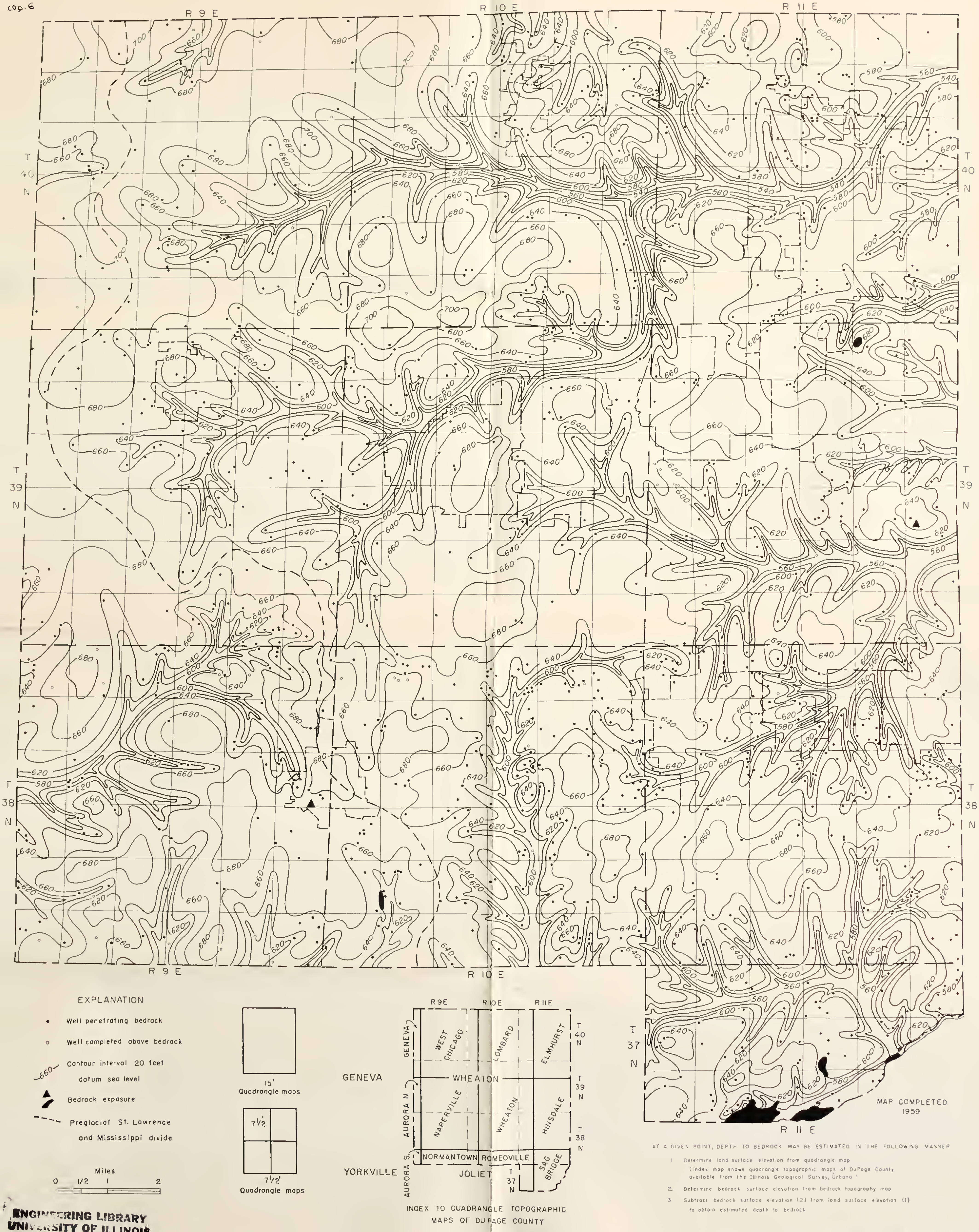

AT A GIVEN POINT, DEPTH TO BEDROCK MAY BE ESTIMATED IN THE FOLLOWING MANNER

1. Determine land surface elevation from quadrangle map (index map shows quadrangle topographic maps of DuPage County available from the Illinois Geological Survey, Urbana)
2. Determine bedrock surface elevation from bedrock topography map
3. Subtract bedrock surface elevation (2) from land surface elevation (1) to obtain estimated depth to bedrock

TOPOGRAPHY OF BEDROCK SURFACE IN DU PAGE COUNTY, ILLINOIS

A. J. Zeizel

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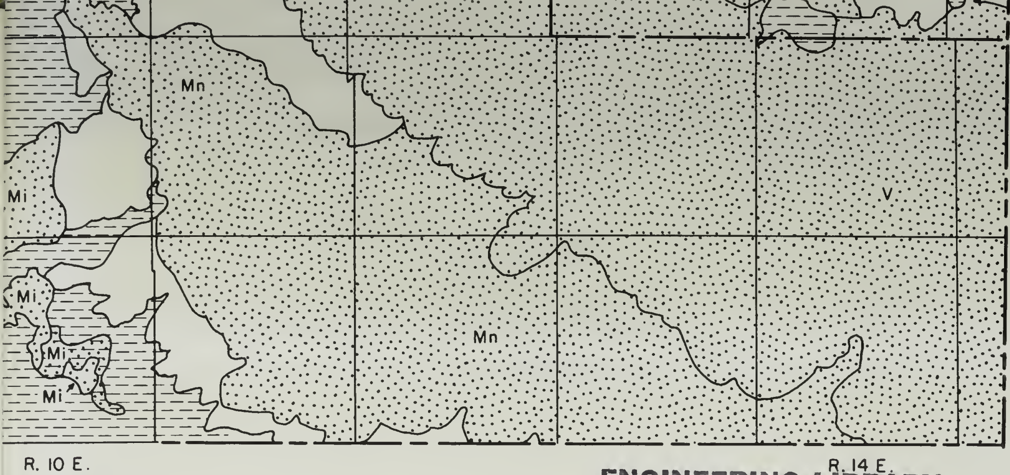

OGY OF NORTHEASTERN ILLINOIS

ORGE E. EKBLAW

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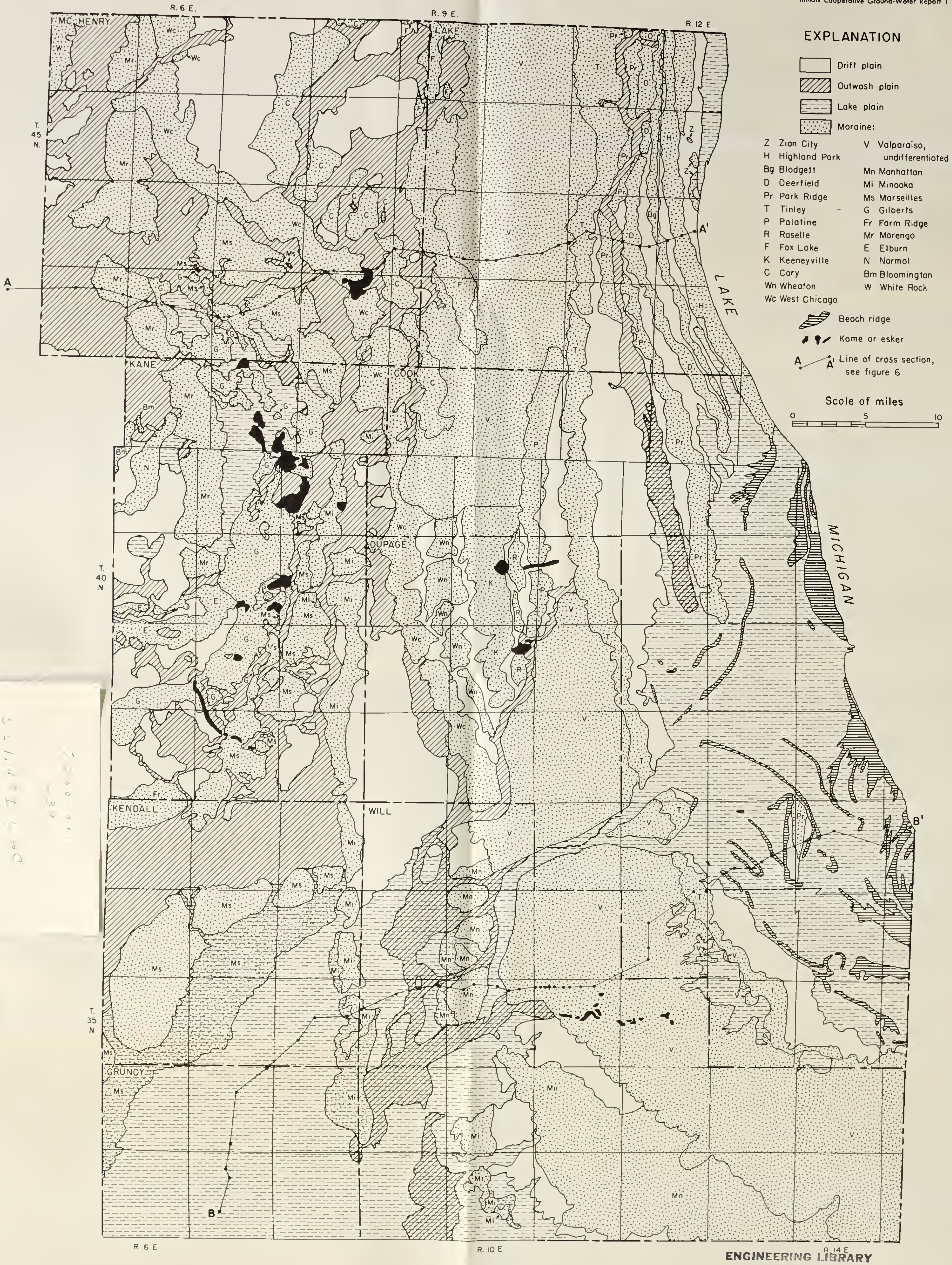

FIG. 5. GLACIAL GEOLOGY OF NORTHEASTERN ILLINOIS

GEORGE E. EKBLAW
Illinois State Geological Survey, Urbana

1959

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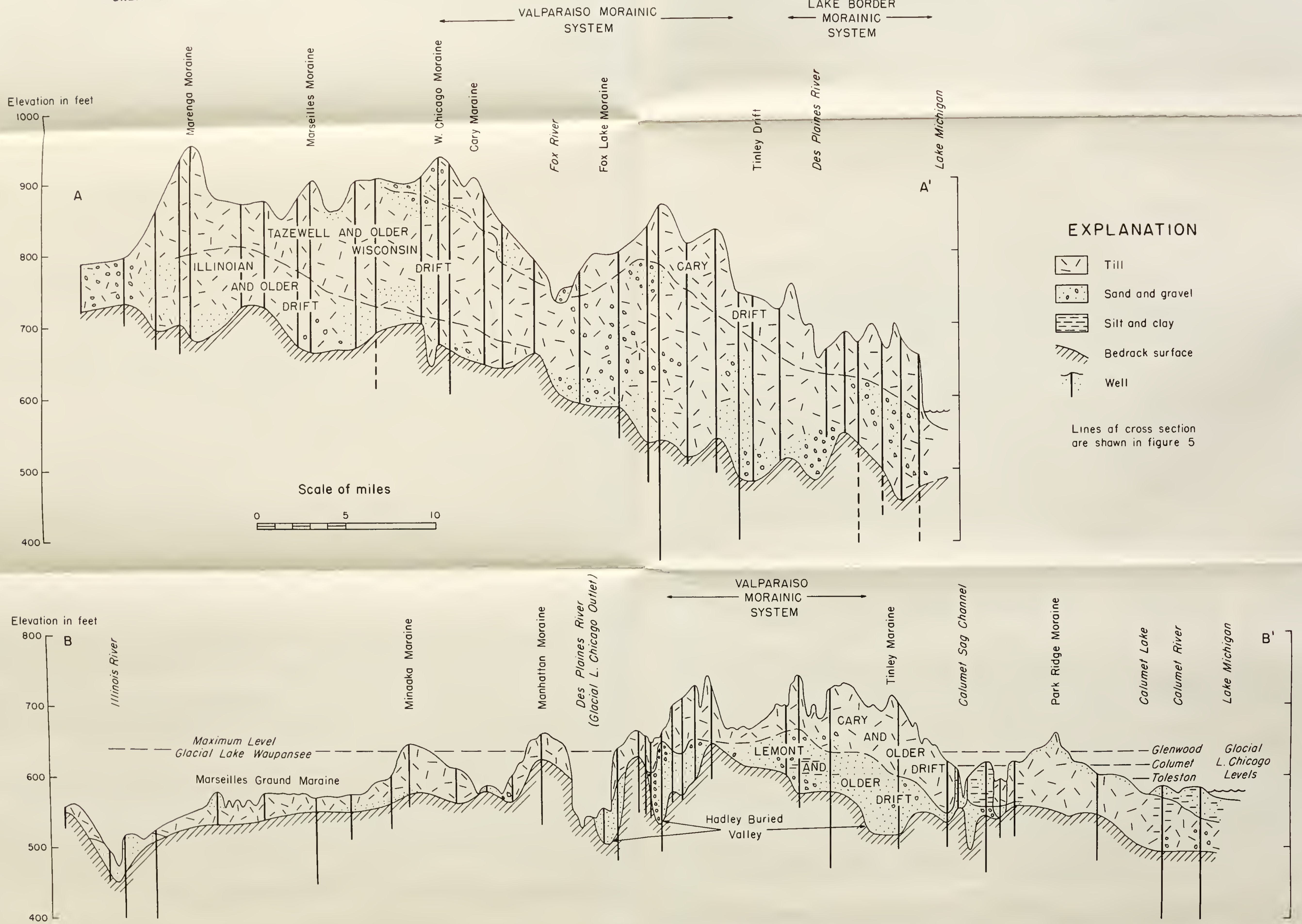

FIG. 6. CROSS SECTIONS OF THE GLACIAL DEPOSITS IN THE CHICAGO REGION

- TOPOGRAPHY OF BEDROCK IN DU PAGE COUNTY, ILLINOIS
- FIGURE 5: GLACIAL GEOLOGY OF N.E. ILLINOIS
- FIGURE 6: CROSS SECTION... CHICAGO REGION

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